SAVE THE CROWN JOULES

NET BENEFITS OF

ENERGY CONSERVATION STANDARDS FOR HOUSING

IN LIGHT OF CHANGING SUPPLIER COSTS

by

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ABSTRACT

Higher energy efficiency standards for housing may delay the need for large-scale power generation facilities. This delay means lower energy costs. In housing, buyers and sellers generally heavily discount future energy costs in the valuation process. This prevents accurate assessment of energy-conserving houses and results in an under-supply of these houses.

Conservation advocates consider regulation of higher standards an efficient policy alternative to new energy supply. Regulation would change the demand for energy-conserving houses which would change the demand for materials. Costs of upgrading may increase or, if scale economies exist, they may decrease. Studies of higher standards have discounted this fact – point estimates of supplier costs have been used. Furthermore, because most new houses in B.C. are built in moderate climates, benefits of conservation may be small. In this study, we analyze net benefits of higher standards in a moderate climate using changing supplier costs.

In analyzing costs and benefits of higher standards, experts were consulted to identify upgrade measures widely available to builders. A computer program estimated heating loads of each upgrade. Three existing houses were used as starting points for analysis. Benefits of energy savings were estimated using avoided energy costs. Upgrade costs were estimated using installation and maintenance costs. Where upgrades increased or decreased floor area, a market cost for adjusted floor area was included. Sensitivity analyses involved using different discount rates, changing supplier costs, and environmental costs of energy.

The study showed that consumers who heavily discount long term benefits of energy conservation would not purchase energy-conserving upgrades. In contrast, a number of upgrades were worth adopting – these

upgrades turned out to be less expensive than new natural gas and electricity supply. This appears to support the value to regulate higher standards. However, analysis of an integrated package of upgrades (i.e., the effect of new standards in a building code) produced mixed results. Benefits of new energy efficiency standards were not robust across a range of discount rates, supplier costs and energy costs. In general, this study found that the integrated package of upgrades would not be worth adopting in most of the cases analyzed.

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DEDICATION

To my wife, Bernadette, for her love and encouragement. To our families for their support. To my son, Stephen, for being there. I love you all.

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CHAPTER 1 INTRODUCTION

Energy conservation may be an efficient public policy alternative to large-scale power generation facilities. If less energy is used, the construction of such facilities can be delayed, and possibly avoided. Delayed costs mean lower costs. In exploring the potential for energy conservation in housing, policy makers have focussed on reducing space heating requirements – in particular, raising construction standards. Building codes have been changed to incorporate higher standards.

Skeptics point out, however, that increased housing prices prevent most home buyers from adopting higher standards. Higher standards mean higher costs for housing. Also, information about the benefits of higher standards is difficult and costly to obtain. Home buyers who might consider buying houses built to higher standards are faced with higher initial costs and insufficient information.

Where estimates about the benefits of higher standards are available, the reliability of computer models used in obtaining this information is questioned. Space heating requirements depend on the behaviour of occupants. For instance, use of a wood fireplace will vary heating requirements of other fuels. Computer models do not account for fireplace use. More generally, computer models frequently do not reflect individual preferences in how space heating is used.

In spite of skeptics' views, however, economic studies of electrically heated homes have shown that higher standards for certain construction measures yield net benefits. A range of electricity prices is often used to provide sensitivity on potential benefits of higher standards, but supplier costs are usually treated as a single point-estimate. These studies neglect to explore the effects of a range of supplier costs. For instance, prices for better insulating windows will change as window technology changes. Furthermore, higher construction standards will change both demand and supply schedules for energy-conserving products, and thus change supplier costs. Net benefits that have been predicted for some of these upgrade measures will vary when a range of supplier costs is analyzed.

This study contributes to the ongoing debate by analyzing social costs and benefits of construction upgrades using a range of supplier costs and energy prices. In doing so, a "focus group" of industry experts was consulted to establish which upgrade measures are widely used, and to determine how such measures are employed in practice. Several building contractors and industrial suppliers were surveyed to establish current costs for these upgrades. From these costs, "reasonable" sensitivity analysis was performed on each upgrade measure.

If energy-conserving housing can yield net benefits, then why have buyers not demanded it? Why have builders not supplied it? The answers may lie in particular market failures. This study opens by considering rationales for regulation and by discussing experience with policies for higher standards.

Chapter two discusses market failures in housing – that is, incorrect energy pricing, myopic purchase decisions, and asymmetric access to information for buyers as well as sellers. Discussion includes arguments that question the existence of some market failures, and thus the need for government intervention. Several remedies involving government intervention are then discussed.

To add an historical context to the conservation debate, chapter three presents selected case studies where government has intervened in the housing market. These studies center on efforts in the Pacific Northwest aimed at improving conservation standards. The Bonneville Power Authority provides close to half the electricity used in the U.S. Pacific Northwest. In the early 1980s, Bonneville Power was charged with implementing higher conservation standards in housing. Two significant policy experiments arose: one, to provide information and incentives to home buyers; and two, to set higher construction standards. The first of these policies resulted in several programs that provided potential home buyers with information on long term benefits of higher housing standards. In addition, cash incentives were given to builders who built to higher standards, and to buyers who bought these houses. Results were disappointing – the rate of consumer adoption for "better built houses" has been slow.

Concerned advocates of conservation standards have turned to regulation measures. For instance, the State of Washington recently passed legislation which sets out minimum insulation standards for different building components, adjusted by three climatic zones.

A similar debate is taking place throughout Canada. The "R2000 Program" provides information to consumers about the benefits accruing from better insulated houses. To builders, the program sets out minimum standards, and also offers marketing support. R2000 homes are thereby differentiated from conventionally built houses. However, the rate of consumer adoption of R2000 houses in Canada has been slow especially in the more moderate climes of B.C. In Canada as in the U.S., policy has increasingly focussed on regulating minimum construction standards. This study contributes to the discussion of appropriate upgrades that could be imposed by regulations.

Chapter four outlines the methodology used in analyzing the costs and benefits of construction upgrades. Discussions with experts in the housing industry helped to identify different upgrades currently used, or available for use, by builders. This "focus group" of experts also provided insights into the materials and methods required by each upgrade. From these discussions, a list of seventeen different upgrades was assembled for analysis. Costs for each upgrade were determined by surveying different suppliers. Their responses also provided a basis for determining a reasonable range of costs for sensitivity analysis. The range used is plus and minus thirty percent of the average supplier cost for each upgrade.

To determine benefits arising from construction upgrades, avoided costs of new energy supply were used. For electricity, this turned out to be 5.7 cents per kilowatt-hour (1992 dollars); for natural gas, 3.25 cents per kilowatt-hour. The first figure represents the cost to supply "firm" electricity from a new set of hydroelectric dams. The second figure represents the peak demand cost to build an additional liquefied natural gas storage facility.

However, many conservation advocates see avoided costs as underestimating the benefits received in energy conservation. To accommodate their perspective, this study also performed sensitivity analyses using social and avoided costs for energy. The social cost used for electricity and natural gas was estimated to be 0.86 cents per kilowatt-hour. This figure uses B.C. Hydro's practice of providing a 15 percent credit to the cost of environmentally benign projects (0.86¢ = 15% x 5.7¢). For natural gas, this figure exceeds estimates presented in a recent study into social costs of supplying natural gas (B.C. Gas 1991). The social and avoided costs used were 6.56 cents per kilowatt-hour for electricity and 4.11 cents per kilowatt-hour for gas.

The energy auditing software program "HOT2000" was used to determine energy savings from construction upgrades[1]. Out of twenty home owners approached to participate in the study, only eleven consented. Eventually, only three houses were used in upgrades analyses. Space heating loads before upgrade were compared with those after upgrade. In each analysis, future costs and savings were discounted to the present to provide a net present value, or net benefit, for each upgrade.

Results can be found in chapter 5. Findings have been tabulated and presented on a house-by-house basis. Overall, net benefits were mixed. Many upgrades yielded positive net benefits. However, heat recovery ventilation and some window upgrades consistently generated negative net benefits. Insulating the foundation of a house turned out positive net benefits in most cases.

Discussion focuses on whether changes to net savings and costs met with expectations. For instance, net savings should increase with lower discount rates. In some cases, the opposite occurred. Causes for these differences are discussed.

Overall, findings were mixed. On one hand, they indicated that consumers generally would not purchase energy conserving upgrades. On the other hand, it was shown that higher housing standards did not consistently yield net benefits. Regulating conservation standards in B.C. housing is not supported by this study.

FOOTNOTES

1 HOT2000 was developed under the direction of the R2000 Home Program of Energy, Mines and Resources Canada. The Canadian Home Builders Association is the sole distributor of HOT2000.

CHAPTER 2 - MARKET FAILURES

2.1 FLAWS IN THE COMPETITIVE MODEL

"If you can build a better mouse trap, the world will beat a path to your door."

(quote from an anonymous economist who believes government regulation unnecessary.)

Energy conservation in housing can be referred to as "better mouse traps". While new products are continually being introduced into the market, many existing products have been available for years. They can all save energy, and thus reduce energy costs. Yet, if energy-conserving houses yield net benefits, why have consumers not demanded them? Likewise, why have builders not built more of them? Answers to these questions may lie in market failures where market signals prompt consumers to make sub-optimal decisions.

An ideal competitive economy is defined where, in equilibrium, a set of prices for factor inputs and final goods clears all markets. The quantity demanded at theses prices coincides exactly with the quantity supplied. This competitive equilibrium is called Pareto-optimal or Pareto-efficient: one person's utility cannot increase without reducing the utility of another.

In an ideal competitive model, price is the governing factor in consumer choices such that the behaviour of utility-maximizing persons coupled with that of profit-maximizing firms will distribute goods in a Pareto-efficient way. Where prices fail to reflect the full impact of consuming a good (or service), market failure occurs which results in either over- or under-consumption of the good. The following discussion limits market failures to three that are relevant to energy consumption in housing: externality, information asymmetry, and consumer myopia.

A. EXTERNALITY

An externality occurs if an unanticipated impact, arising out of producing or consuming a good, affects third parties who are not consenting to the transaction. Consider the case of using leaded gasoline in automobiles. One effect of burning leaded gasoline is that lead remains in the air which, when inhaled, can lead to adverse health effects. This consequence was obviously not intended in the original transaction between producer and purchaser. The price for gasoline could not have incorporated the adverse effect of lead in the air, thus a "negative externality" arose[1].

B. INFORMATION ASYMMETRY

Another type of market failure is known as "information asymmetry". Information asymmetry occurs when information about a good (or service) is available to one side of the market, but withheld from the other even though the benefits received from having such information exceed the costs of providing it. For instance, manufacturers of refrigerators have accurate estimates of the life expectancies of different compressors, much more so than do consumers. Some compressors will last 5 years on average, others 10 years. Such information is necessary in establishing warranty policies, and is available to manufacturers and their agents. This information would also be useful in swaying the consumer between model X (with the 10-year compressor) and model Y (with the 5-year compressor). It would cost practically nothing to provide this information, but in not doing so the manufacturer prevents the buyer from accurately assessing longer term costs (and benefits) in her purchase decision. There is no assurance that the buyer, when informed of average lifetimes for model X and the less expensive model Y, will choose the model with the greater life expectancy. She may still choose the cheaper model Y. The substantive point of the exercise is that her choice be based on a rational decision process which involves the examination of long term operating and replacement costs. The buyer is prevented from making such a rational decision where relevant information is withheld.

C. Myopia

Yet another type of market failure arises when agents exhibit a very high discount rate in making purchase decisions. This is referred to as "myopia". A useful case in point lies in cigarette smoking. Nicotine addiction and respiratory ailments are not desired outcomes when first purchasing cigarettes, but the need to satisfy the former soon becomes the motive for continued cigarette consumption. Information campaigns and warning labels have been used to warn smokers, and potential smokers, of the long term adverse health effects of smoking, but in spite of such actions the number of first-time cigarette smokers continues to increase[2]. Smokers seem to discount the future heavily, that is they choose to satisfy an immediate need while ignoring the long term, self-imposed risks. It is this preference for utility maximization under a very short time horizon that is characteristic of myopia.

2.2 MARKET FAILURES IN BUYING A NEW HOUSE

In the housing market, the process of choosing and finally purchasing a house usually involves several agents. The seller engages a real estate agent (referred to as a realtor). The mortgage lender approves, or denies financing based on personal financial information provided by the potential borrower, building inspection information provided by an inspector, and property value information provided by an appraiser. The buyer may, or may not, choose to engage a realtor separate from that of the seller. Often, the buyer will not seek technical information about the house(s) being considered.

Consider the case of one young couple about to finalize the purchase of a house. Weeks of viewing different houses have culminated in this moment where they sit, face to face, with a realtor in the house of their choice. The dialogue might go something like this:

Her: "It looks good. I like the layout of the kitchen. There's plenty of rooms to have both a guest room, and a study."

Him: "The yard is a good size, but the garage could be larger. The bathrooms are spacious, though."

Turning to the realtor, she says, "You say that this house is heated using natural gas, but I've heard that the insulation in walls and attic matter a lot in how much energy we'd use. Do you know what the insulation is like in this house?"

Realtor: "Well, this house was built by a highly respected developer. I know of many satisfied buyers who have purchased homes built by [him].

"I can't imagine that [he] would provide anything but the highest quality materials in building this house. But, seeing as you are concerned about this matter, I'll find out for you."

Her: "Thank you. I'd appreciate that. One more thing, do you think a building inspection would be a good idea?"

Realtor: "It's always a good idea to get a technical opinion, but bear in mind that this would cost you an additional three to five hundred dollars. Your bank will inspect the house before your mortgage gets approved, anyway."

Two points arise out of this hypothetical (albeit realistic) encounter. First is that information can be obtained as a good. The couple can see for themselves what features they were buying, or they can purchase information by hiring a building inspector. Second, information about a good can be obtained so that benefits derived from using the information exceed the costs incurred in obtaining it. The realtor might have known about the insulation characteristics in the house, but was afraid of complicating or jeopardizing the deal by prematurely offering information. If the realtor did not know, the builder or developer should have known, and could have made the information available at little or no cost.

A. Information As A Good

The first point, information *as a good* , entails finding an efficient price so that relevant information is provided. Information can be "consumed", that is it can be used, by more than one person at one time. In the example, the bank's building inspector would be paid to get the information on the house. Once obtained, the benefits could be made available to all consumers and the marginal cost of doing so is practically zero. However, this information is still incomplete – long term costs are not included in the analysis. Does a market failure exist if further information about conservation is not sought?

Sutherland (1990, p. 21) speaks of high transaction costs faced by consumers as preventing information availability. He rightly points out that high costs in obtaining information are not market failures. Consumers regularly face high transaction costs in obtaining information yet they make purchase decisions in spite of the resulting uncertainties. The substantive point in the above conversation between realtor and potential buyer is that markets may fail to provide equal access to information once it has been made available. This is commonly referred to as "information asymmetry".

B. Information Asymmetry – Information *About* A Good

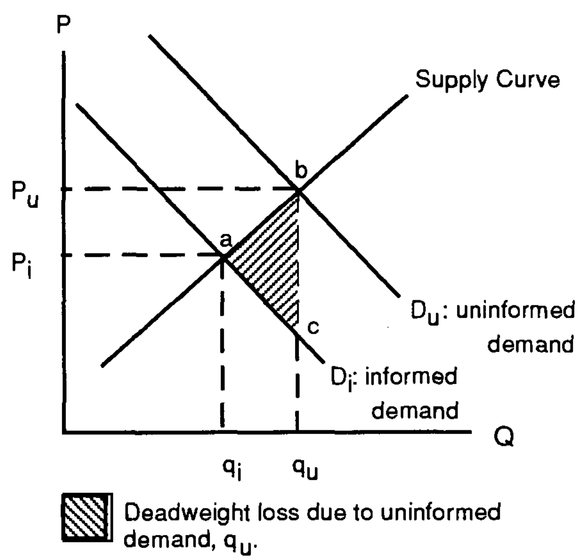
Information *about a good* affects the purchase decision for that good (or service). For instance, the long term cost to heat the house might alter the buyer's perception of the house's value. Sellers usually possess more information about the integrity of the house's envelope and heating systems than do buyers. If buyers were fully informed about the quality of houses, exhibit 2.2A shows that they would consume 'q_i' units of housing at price 'P_i'. Information asymmetry prevents potential home buyers from purchasing along the 'informed' demand curve, 'D_i', and instead forces them to buy 'q_u'

units of housing. The excess consumption (q_iq_u) results in a marginal cost equal to the area 'q_iabq_u', and a marginal benefit equal to the area 'q_iacq_u'. A deadweight loss arises equal to the triangular area 'abc'. Greater Pareto efficiency would arise if better information about houses were provided to consumers.

B1. HOME OWNERS LEARN FROM EXPERIENCE

At this point, it would be useful to classify the kinds of goods that home buyers face. Goods can generally be considered as *search goods, experience goods,* and *post-experience goods* [3]. The qualities of a *search good* can be determined prior to purchase. Search costs are relatively small compared with the price of the good. For instance, a pen can be examined and found either useful or not useful before purchase. Inefficiencies rarely arise from information asymmetry in search goods because consumers can readily purchase competitor's goods, such as another brand of pen, or substitutes, such as a pencil.

Exhibit 2.2A Loss to social surplus arising from uninformed decision-making



Experience goods entail both search costs and full purchase costs[4]. The quality of the jazz concert, for instance, cannot be fully determined until the ticket has been purchased and the concert begins. In a similar vein, the *post-experience good* requires at least search costs and purchase costs, but the full costs of consuming the good are often delayed so that consumers do not readily identify them with the good. Smoking cigarettes is one example. Nicotine addiction is not a desired outcome when the good is first purchased and consumed. The potential for inefficiencies due to information asymmetry in experience and post-experience goods is high. In situations such as buying a house, the relative infrequency with which consumers purchase such goods means that inefficiencies will persist for long periods of time.

It would be difficult for a new house buyer to perceive the full cost of the house before purchase. In some instances, houses have been purchased solely on the basis of viewing design drawings at the construction site. Factors relating to the level of comfort inside the house cannot be measured until after the house is occupied. Space heating requirements cannot be determined before the heating bill that follows the onset of cold nights. The integrity of the house envelope at retaining heat cannot be determined for many years. Monthly savings that result from incorporating energy-conserving components may be realized soon after the house purchase. However a home owner might not directly link her higher disposable income to the initial investment in energy-conserving technologies. Buyers of new houses therefore discover the quality of their purchase long after the purchase has been made. This makes it difficult for the consumer to realize benefits of purchasing an energy-conserving house or product at the time of purchase. The incentive for providing additional information is left undefined. Information asymmetry persists, and consumers continue to over-consume the conventionally built house[5].

B2. Problems With Secondary Markets For Information Asymmetry

Consumers and producers often turn to "secondary markets" to help remedy information asymmetry (Weimer and Vining 1989, p. 73). Real estate agents, or realtors, serve this purpose in the housing market. Realtors engage in many transactions between different pairs of buyers and sellers. They package this expertise as advice, and sell it along with their services in searching out alternate houses. However, a realtor's advice usually ignores information about the thermal integrity of a house.

For instance, one of the many tools available almost exclusively to realtors is the "listing service". The listing service is a compilation of houses available on the market. The scope of a listing can be regional, national, or even international. Its content regarding a specific house includes information on geographic location, exterior layout, interior floor plan, and existing heating or cooling systems, but no reference is made to efficiencies of such systems, nor to insulation characteristics of the house envelope. Information contained in the listing service reflects industry's attitude toward what constitutes relevant information. The absence of information about thermal integrity and space heating energy requirements implies a general disregard among realtors for such information. Even if a realtor were conscientious about energy conservation, she would find it costly (in time and dollars) to obtain the necessary information, and would probably avoid doing so.

Realtors are not solely to blame for the lack of attention paid to space heating and thermal integrity. The potential house buyer provides little incentive for realtors to incorporate such information. The buyer generally does not think of space heating requirements while she decides on whether to buy a house. Providing such information might be seen by a realtor as unnecessarily complicating, or possibly negating, a sale. Realtors therefore contribute little to remedy information asymmetry in energy-conserving housing.

B3. THE LENDER'S ROLE AT RESOLVING INFORMATION ASYMMETRY

Lending institutions could play a significant role in remedying the information asymmetry between buyers and sellers. In order to assess the risk of a mortgage, lenders require extensive information about both the borrower's financial situation, and the value of the property in question. The mortgage applicant typically provides information about her income level, spending habits, and current debts, from which her ability to service a mortgage is determined. The property in question is inspected and its value appraised in order to determine its collateral value. Approval or rejection of a mortgage is then based on the applicant's debt-servicing ability, and the appraised value of the property.

However, lenders have traditionally ignored the effect that energy-conserving technologies have on operating costs, and therefore on the borrower's ability to service debt. Building inspections generally do not include information on expected costs to operate heating (or cooling) systems, or any other systems for that matter. Technical advice is incomplete, and therefore long term costs and benefits of energy-conserving technologies cannot be easily evaluated. Neither building inspectors nor property developers (or their engineers and architects, if any) are required to provide assessments of annual operating costs in residential dwellings. As a consequence, the magnitude of savings[6] that arises out of purchasing an energy-conserving house is not recognized, resulting in an inaccurate assessment of the buyer's repayment capability.

This is not to say that the lender is at fault in ignoring energy savings. As is the case with realtors, lenders determine a property's worth on the basis of what the market considers valuable. However, where realtors deal with selling and buying a house (a transaction at a point in time), lenders are concerned with the borrower's ability to repay the mortgage (a series of transactions through time). Savings that result from energy conservation impact directly on the borrower's ability to meet mortgage payments. Incentive therefore exists for lenders to incorporate the presence of energy-conserving technologies into their assessment of mortgage applications.

Attempts have been made to incorporate heating expenses, for instance, into the mortgage application process. One chartered bank[7] has recently introduced a mortgage plan that offers a reduced borrowing rate if the house meets energy efficiency standards set out in the R-2000 Program. Consumer response to such a plan is not yet available – the plan was only recently introduced.

Mortgage insurance offered by the Canadian Mortgage and Housing Corporation (CMHC) requires that heating expense be included as part of its underwriting equation. However, mortgage insurance is only required for "high-ratio" mortgages, that is mortgages in excess of 90 percent of the purchase price. CMHC's requirement has little impact on conventional mortgages (Hee 1993, p.8).

In general, the housing industry leaves energy-efficient technology to valuation by the market. If consumers truly prefer energy-efficient housing, then market prices will reflect this preference. However, markets can only value a goods efficiently if information "symmetry" exists for both buyers and sellers. Information asymmetry occurs in the housing market at the technical-financial boundary. The inability, or unwillingness, of one side to convey information, and the other side to incorporate it, perpetuates inefficient consumption levels for energy-conserving technologies and housing.

C. Inaccurate Prices For Energy – Externalities

In the context of housing, negative externalities arise from excessive energy consumption. Natural gas is one form of energy commonly used in space heating. In British Columbia, hydroelectricity is another. Consumption of these energy forms adversely affects the natural environment. Externalities arise because the price paid for consumption does not incorporate impacts on the environment.

Throughout the production and consumption cycle of natural gas, emissions are released into the air. Of these air emissions, carbon dioxide and methane gas contribute to the gradual warming of the earth's climate[8]. Other emissions reduce air quality, and contribute to acid rain. Since costs of these impacts to the atmosphere are generally not included in the consumption price, externalities exist in the production and consumption of natural gas.

Production of hydroelectricity also impacts on the natural environment. Hydroelectric generation necessitates the destruction of "unique resources" such as large areas of wilderness which, in turn, disrupts whole ecosystems, and reduces silviculture stocks[9]; subsequent changes to river flows impact on aquaculture as well. Resources such as wilderness and animal species have no value as factor inputs, or as final goods, in the energy equation. The result will most probably be over-consumption of unique resources. Markets fail in hydroelectricity because unique resources are not valued in the final price paid by consumers.

The presence of externalities in energy consumption ensures that market prices will not accurately value the good(s) in question. If externalities were to be captured, the result would be higher prices for energy, and lower demand for energy-inefficient houses. Currently, prices for energy understate the value of energy-efficient houses, and signal the consumer to over-value the energy-inefficient house.

D. SHORT-SIGHTED MARKETS: MYOPIC BEHAVIOUR BY HOME BUYERS

The question of whether competitive markets can distribute goods efficiently over time predicates itself on the existence of reasonable intertemporal prices. Prices for tradeoffs between current and future consumption are market interest rates. Real market rates (also referred to as 'discount rates') range from 3 percent for "low risk" investments to 10 percent or more for "riskier" investments. Consumers have been shown to exhibit implicit discount rates in excess of 30 percent. If such implicit discount rates exceed the range of socially "acceptable" market rates, then consumers can be said to be myopic in making purchase decisions.

In an ideal competitive market, the discount rate that reflects society's view of current and future consumption (referred to as the 'social rate') equals the market rate (Weimer and Vining 1989, p.84). This assumes that forward markets exist for all goods, and transaction costs are insignificant. However, uncertainty plays a key role in raising market rates above the social rate. For instance, a contract sets out requirements for compensation in the event that a borrower is unable to meet its terms. Bankruptcy laws, however, render uncompleted contracts unenforceable. Lenders will therefore require higher returns on riskier investments, a kind of risk premium[10], which effectively raises market rates above the social rate.

The range of market rates for public, corporate and private investments embody generally acceptable levels of risk to society. Government bonds are generally considered free of default risk, and representative of the lower range for acceptable market rates. Government long bonds offer real annual rates of return in the range from 3 to 6 percent

(Dept. of Finance 1993, p. 40[11]). Investments in common stocks establish a "benchmark" upper end for acceptable market rates. W.F. Sharpe (1985) found that the average (real) rate of return on common stocks from 1926 through 1982 was 11.58 percent (Sutherland, 1990). A socially acceptable range for risk can be said to exist from 3 to 12 percent (real rates of return). Yet, even the 12 percent upper end is far below the implicit discount rates used by many consumers.

Consumers display implicit discount rates when making choices having intertemporal effects. In one study, participants at a home renovations trade fair were surveyed about their willingness to purchase energy-conserving technologies. Results indicated that implicit discount rates exceeded 20 percent; in some instances, discount rates exceeded 30 percent (Richards and Sims 1989). Other studies have found similar discount rates[12] among consumers of energy-efficient products (Hausman and Joskow 1982, p. 221; Dubin and McFadden 1980). Further evidence of high consumer discount rates can be found among many bank credit card holders. Interest rates in the case of bank credit cards have reached, and exceeded, 20 percent (real). In spite of these high rates, card holders continued to borrow to the limit. Consumers in these cases exhibit implicit discount rates that greatly exceed the socially acceptable range for market rates – they exhibit myopia.

In such cases, dramatically different perspectives will arise between the consumer and society in terms of preference for energy-conserving technologies. For instance, house "A" costs $3,000 more than house "B". The two houses are architecturally and geographically identical for all intents and purposes, but house "A" was built to higher energy-efficiency standards. The energy-efficient house saves $400 per year in energy payments. Exhibit 2.2B shows that, using a market rate of 3 percent, the net benefit of choosing house "A" is $10,333[13]. A market rate of 12 percent yields a net benefit of $333. The market segment that exhibits a 20 percent implicit discount rate sees net benefits of *negative* $1,000.

Energy savings in this example yield (positive) net benefits when socially acceptable discount rates (i.e. 3% and 12%) are used. Consumer preference, however, indicates that these energy savings are insufficient; she would choose the less energy-efficient house.

Exhibit 2.2B Perceived benefit of $3000 added investment in house "A" which yields annual savings of $400.

Viewpoint	Discount Rate, r	NPV*
Low Market Rate	3%	$10,333
High Market Rate	12%	$333
Consumer's Implicit Rate	20%	–$1,000

* Net Present Value = $\frac{\$400}{r} - \$3000$.

In the case of energy conservation investments, Sutherland (1990, p.18) discounts myopia as a cause for market failure, and instead shifts the argument to uncertainty premiums. He points to the uncertainty of predicting energy prices (and hence, the savings from reduced energy use) as being much like forecasting common stock prices. Uncertainty in forecasting energy (or stock) prices constitutes a normal investment risk, and translates into higher discount rates[14]. High implicit discount rates, therefore, are indicative of high risk, and not myopia. Nevertheless, Sutherland notes that inefficient investment decisions may still result if consumer decisions are made using consistently biased price forecasts.

Government intervention provides a possible solution when differences arise between society's preference, and consumer preferences in making intertemporal allocations of (say) energy. Such intervention effectively ignores consumer preference. Advocates of government intervention in this case are behaving paternalistically, wanting their view of the market to supersede that of the consumer.

2.3 REMEDIES – OPTIONS AVAILABLE THROUGH PUBLIC INTERVENTION

Where market failures occur, public intervention offers the possibility for remedy. In the context of energy consumption and housing, public intervention can take several forms. It can facilitate markets to achieve optimal production levels of externalities. It can change incentives by imposing taxes, and offering subsidies. It can establish standards both to disseminate information, and to enforce product quality.

A. FACILITATING MARKETS BY ASSIGNING PROPERTY RIGHTS

Public intervention can facilitate a market where the rights to produce and consume (or receive) externalities are traded. This is known as assigning "property rights". A property right relates to the right to use a resource. The "Coase Theorem" (after Ronald Coase, 1960) contends that a competitive economy will allocate resources efficiently, despite seemingly important externalities, so long as, one, all relevant rights are allocated and transferable; and, two, transfer of these rights can be carried out at little or no cost (Mansfield, p. 508). Externalities that impact on public goods, such as air and water resources, can affect a large number of groups. Some groups may not be easily identifiable, and their respective right may be unclear. Coase's provision that negotiations must take place at relatively little or no cost becomes important when one considers the difficulties, hence costs, involved in identifying all affected groups, and negotiating between them.

B. ALTERING INCENTIVES USING TAXES AND SUBSIDIES

Both taxes and subsidies can be used to alter incentives facing home buyers, and thereby change behaviour. When transaction and coordination costs obviate negotiated solutions (vis-à-vis Coase's theorem), taxes and subsidies give government the potential for correcting market failure.

B1. PIGOVIAN TAX ON NEGATIVE EXTERNALITIES

In theory, a per unit tax raises the price of a good (or a bad as in this case) such as methane gas emissions, and thereby internalizes the negative externality. The concept that taxes can be used to internalize externalities is referred to as a "Pigovian tax solution"[15]. A tax affords flexibility to producers and consumers. So long as firms (or consumers) see the same tax, the industry (or market) as a whole reduces externalities in the least costly way to society (Weimer and Vining 1989, p. 135). Problems arise, however, in trying to establish the marginal cost of an externality-generating good, and hence the right tax.

In order to find the optimal level of externality, information is required to determine the shape of social cost and social benefit functions. Difficulties arise in trying to identify and monetize impacts from externalities (see the earlier discussion on public goods). In addition, information about the costs of doing business in the housing industry, for instance, is generally confidential or not available. In reality, what may be of interest is not finding the optimal level of externality, hence tax, but rather determining the right direction of change (Turner and Pearce 1990, pp. 85-6).

B2. SUBSIDIES TO SUPPLIERS AND CONSUMERS

While per unit taxes internalize negative externalities, per unit subsidies internalize positive externalities. Subsidies directed toward increasing the supply of energy-conserving houses generate positive externalities via reduced external costs from energy consumption.

In the context of energy conservation and housing, cash subsidies can be given as reimbursement to buyers of energy-conserving houses. Given that housing markets tend to be local, and short run supply schedules upward sloping, an increase in demand for energy-conserving houses should, in the short run, stimulate a rise in their price. This, in turn, would signal to builders to enter the industry – driving up the supply of energy-conserving houses and driving down price. In reality, though, consumers who pay over one hundred thousand dollars for a house may not see conservation subsidies of a few thousand dollars as significant. It is unclear therefore whether such subsidies change housing markets at all (Weimer and Vining 1989, pp. 144-5)[16].

C. Regulation By Setting Standards

Where taxes and subsidies afford flexibility, that is adjustments can be made by firms and individuals to better achieve Pareto-optimality, standards are fairly inflexible. One common form of regulation in housing is to set construction standards that require the use of energy-conserving techniques and materials. In the past, standards have generally been established with regard to health (setting acceptable levels of air-borne toxins), fire safety (setting fire-ratings for walls), and personal safety (stairwell design). Once a standard has been established, large public investment ensues aimed at enforcing such standards.

The virtue in setting standards lies in certainty of outcome, especially where the cost of error is great. For instance, underestimating the cost of flooded valleys or global warming may result in irreversible, and possibly catastrophic consequences. It would be desirable in such instances to restrict dam construction directly instead of relying on the iterative process of economic incentives.

Setting standards entails monitoring and enforcement which requires additional cost. In housing, such agencies already exist. Construction cannot proceed without first seeking the necessary permits. The structure must meet building code standards before it can be occupied. Establishment of new standards, such as energy conservation, would require only the additional cost to upgrade enforcement personnel training.

D. REGULATION BY PROVIDING INFORMATION TO CONSUMERS

It was noted in the earlier discussion about information asymmetry that the time lag between purchasing a good and determining its quality can, in many instances, be long (e.g., the effects of choosing urea-formaldehyde insulation are not evident until many years later). Since information asymmetry suggests that information exists which is relevant to buyers and sellers, but only one of these parties possesses the information, the question arises, "How can this information be made available to the other party?"

D1. GOVERNMENT AS A SOURCE

Government is one source of information. For instance, the National Research Council acts on behalf of Canadians in testing products both to establish standards (for new products), and to determine compliance with existing standards. A product that complies with established standards is labeled as approved. The initials "CSA" are familiar to Canadians as denoting approval by the Canadian Standards Association. Actual test results, however, are often not published even though the marginal costs of providing the information are small. Instead, the task of disseminating information to consumers is generally left to firms that produce the good (and also to consumer advocacy agents who publish their own test findings in trade and consumer journals). One variation on government-provided information is to require that producers supply the information. Appliance energy-efficiency labeling, automobile mileage ratings, and health warnings on cigarette packages are some examples of mandatory information.

D2. CERTIFYING GROUPS TO PROVIDE INFORMATION

In industry, the quality of services can change much faster than the quality of products. It would not be practical for government to monitor activities in every industry, nor would it be likely that government would employ experts from all industries who could predict the potential for change arising from such activities. A common approach to solving this problem is to license or certify providers of information on the basis that they meet some standard of skill, experience, and training[17].

Licensure legally excludes unlicensed practitioners from practising in the trade or profession. *Certification* bestows a special designation or certification which other practitioners cannot legally use, but which does not prevent uncertified practitioners from providing the same services. In the housing industry, engineers and architects must be licensed in order to represent themselves. However the service of building a house does not require such licensure. Neither is certification a requirement. Anyone is permitted to build a house provided the structure meets established standards and by-laws. The problem of distinguishing houses built to energy-conserving standards has given rise, in Canada, to certification of "R2000 builders". In this way, the tasks of providing information about energy-conserving houses and ensuring that quality is maintained are passed onto certified builders and their representative associations.

However, neither mandatory information nor creation of certified or licensed groups solves the problem if other market failures are relevant. If consumers heavily discount future events, then no amount of information about long term benefits will matter. Looking to increase the adoption of energy-conserving houses by providing better information simply begs the question of the relevant failure.

E. Caveat – Effect Of Interest Groups On Decision-Making

The overall mandate for governments to maximize social welfare can fall prey to the personal interests of elected representatives. Such interests are often articulated as serving the public good, but in practice serve to benefit a very select group – the representative's constituency is one such group. Individuals within society who see the possibility of concentrated benefits accruing to them at little cost (by, for instance, organizing a lobby) will form alliances, or direct existing alliances, to search out these benefits. These alliances are referred to as "special interest groups", or simply "interest groups".

Interest groups that have arisen in the housing industry seem to focus on two themes, adjustment costs for industry and replacement costs for new energy sources. The "cost of doing business" is a going concern in groups such as home-builders associations and real estate boards. Adoption of energy-efficient technologies into building codes increases the cost of construction. Higher construction costs will force builders on the margin to leave the industry. Consequently, home-builders associations act to resist any measures that might increase costs.

Realtors play a large role in the housing industry. Realtors operate on the basis of maximizing sales volume – the more units that are bought and sold, the better. Changes such as the adoption of energy-efficiency measures which may increase housing costs and reduce sales volume have been actively opposed by real estate boards in the United States (Hee, p. 15). Since energy-efficient housing is viewed as an unnecessary complication in the sale of a house, it would be safe to assume that local real estate boards might act in a way similar to their American counterparts.

Advocates of low-cost housing constitute another interest group that will look unfavourably on energy conservation standards in building codes. Higher costs of building houses, albeit only higher if long term heating costs are ignored, will increase house prices. This runs contrary to the goal of "low-cost housing" groups.

More generally, decisions on energy pricing affect many different interest groups. These interest groups stand to lose if projected energy prices are increased. Interest groups are thus motivated to lobby against energy price increases. To the extent that energy prices are politically administered, interest groups may prevent optimal price decisions from taking place. The cost of allowing interest groups to sway policies in favour of low energy prices lies in higher costs for new energy supply and external costs discussed above. By remaining silent on this issue, the public unwittingly endorses the position of these interest groups[18] (McLean 1987, pp. 64-5).

Housing standards can play a significant role in reducing energy consumption. In practice, many governments have intervened in the housing industry to encourage energy conservation standards. The next chapter provides an historical context to the ongoing debate about whether energy consumption should affect housing standards.

FOOTNOTES

1 Air pollution is generally considered a negative externality. One example of a positive externality might be the pollination benefits received by an orchard owner who is situated next to a beekeeper.

2 Teens appear to be most susceptible and attractive to cigarette advertisers.

3 Philip Nelson introduced the distinction of 'search goods' and 'experience goods', "Information and Consumer Behavior," Journal of Political Economy, v. 78, n. 2, Mar/Apr 1970; while Weimer & Vining distinguish a third 'post-experience goods' category, Policy Analysis ..., Prentice-Hall, New Jersey, 1989, pp. 74-5.

4 Full purchase costs include expected costs for failure or damage arising out of consumption for the good.

FOOTNOTES ...

[5] Or under-consume energy-efficient technologies.

[6] Savings for space and water heating can exceed hundreds of dollars annually for a family of four living in a conventionally-built, two thousand square foot house.

[7] The Bank of Montreal.

[8] Carbon dioxide and methane gas are considered to be "greenhouse gases". See R. Byers 1990.

[9] This has both economic, as well as environmental impacts in that marketable timber is lost while, at the same time, the stock of carbon dioxide sinks is reduced. See J. Murray 1992, pp. 17-18.

[10] Another rationale for high market rates is based on the lender's perception that borrowers are myopic in making purchase decisions. That is, a borrower could borrow large amounts, and justify it on reasons and circumstances known only to him or her. The lender, not privy to the unique circumstances (for that matter, she or he may not even consider them important), considers the borrower myopic, and uses high discount rates and rationing to discourage excessive borrowing.

[11] Rates are quoted as real rates.

[12] Dubin & McFadden found an average discount rate of 20 percent for space and water heating appliances.

[13] The formula for a perpetuity is used here. NPV equals the $400 benefit divided by the 3 percent discount rate, and minus the $3000 initial investment.

[14] One counterpoint to Sutherland's argument that deserves particular attention is the question of over-development versus under-development. Energy consumption impacts on "unique" resources such as wilderness areas, animal species, and air quality – resources that have value to society in their existence, but no value as factor inputs in the process of supplying energy. Myopic decisions to buy energy-inefficient houses will result in greater demand for energy which will prompt suppliers to develop new sources of energy earlier. This, in turn, depletes unique resources. Where over-development of energy sources has occurred, unique resources will have been unnecessarily depleted. It is possible for energy suppliers to increase development of new energy sources; it is not possible to decrease such development since it is not feasible to restore unique resources. From a social perspective, somewhat slower development of energy supply may be justified in reducing the risk of excessively depleting unique resources.

[15] Named after Arthur C. Pigou (1877-1959) who was Professor of Political Economy at Cambridge University from 1908 to 1944. He proposed, in Economics of Welfare (first published in 1920) that private and social costs could be equated through taxes.

[16] Weimer and Vining (1989) cite a review by J.A. Hausman and D.A. Wise of a study done by the U.S. Department of Housing and Urban Development.

FOOTNOTES ...

17 "Contracting out" to external consultants can provide government with a means for securing expert advice, and yet without the costs of keeping them on staff.

18 Writings of Mancur Olson as interpreted by McLean in Public Choice (1987).

CHAPTER 3 – SELECTED CASE STUDIES

In the Pacific Northwest region of the U.S., much effort has been made at persuading home buyers to choose energy-conserving houses. The Bonneville Power Administration, charged with implementing conservation standards in housing, developed demonstration programs to inform consumers of the benefits in choosing energy-conserving houses, and incentive programs to entice consumers to buy these houses. Response has been disappointingly slow. Consequently, some states have legislated conservation standards for new homes; Washington State is an example.

In B.C., efforts at upgrading construction standards have followed a similar path to those in the U.S. Pacific Northwest. The R2000 Program encourages potential home buyers to consider buying energy-conserving houses. Certified R2000 builders must learn methods of building energy-conserving houses, and demonstrate competence by building a house to R2000 standards. Potential home buyers receive information on the long term benefits of reduced energy consumption. Similar to Bonneville Power's experience with demonstration programs, consumer adoption of R2000 has been slow, especially in the moderate climes of B.C.'s Lower Mainland and Vancouver Island. Advocates of energy conservation have thus turned their attention to the prospect of regulating higher construction standards.

This chapter studies the two policy strategies (i.e. information and regulation) in B.C. and the Pacific Northwest. In particular, proposed changes to B.C.'s building code are compared with standards in the 1991 Washington State Energy Code.

3.1 THE WASHINGTON STATE ENERGY CODE

BACKGROUND

The Pacific Northwest Power Act (Power Act) was legislated in 1980, creating the Pacific Northwest Electric Power and Conservation Planning Council (later referred to as the Northwest Power Planning Council). The Council's primary objectives were two-fold (Bonneville 1990):

1) To plan the effective and efficient use of all electricity generated by publicly owned dams in the Pacific Northwest; and
2) To assure wise power plant investments.

The result of the Council's planning was the Northwest Power Plan. In it a set of standards known as the Model Conservation Standards (MCS) was adopted to serve as guidelines in residential and commercial construction.

The Council's mandate was restricted to planning; implementation was made the responsibility of the Bonneville Power Administration. Neither possessed regulatory authority. Adoption and enforcement of building code changes rested with state and local governments. The first conflicts came when the Council mandated Bonneville Power to place a surcharge on residential electricity use in jurisdictions where MCS were not met. State and local governments protested. Opposition to the Power Plan centered around the need for time. Industry needed time to educate buyers on the benefits of greater energy efficiency; builders needed time to spread out the increased costs of construction; governments needed time to train inspectors in the new code. Eventually, the surcharge was canceled, and the January 1, 1986 deadline for code adoption was postponed.

PROVIDING A BACK-DROP FOR CODE ADOPTION

As a substitute for direct regulation, Bonneville Power had implemented incentives programs and information programs, to gain acceptance for MCS. The Early Adopter Program started in 1983 (later renamed the Northwest Energy Code Program), and the Super Good Cents Program started in 1985. The Early Adopter Program subsidized local governments for training inspectors, and for certifying homes that met MCS. By targeting subsidies at potential regulators, it was hoped that sufficient numbers of local governments would adopt MCS and set the foundation for building codes to follow (Hee 1993)[1].

The Super Good Cents Program targeted the home buyer and the home builder. Compensation was paid to one or the other for a portion of the incremental cost of building a house to MCS. Offered through electrical utilities, the program paid up to $2,000 (US dollars) for energy efficient homes. Additional amounts were made available to accommodate different occupancies and dwelling types: $750 toward the installation of a heat-recovery ventilator, and $500 toward each additional unit in a multi-family dwelling.

Two demonstration programs provided "hands-on" comparisons between energy-efficient housing and conventional housing. The Residential Standards Demonstration Program (RSDP) served to demonstrate and refine MCS. Started in 1984, over four hundred homes have been built in 3 climatic zones that spanned the Pacific Northwest states. Energy use was established for each home through monitoring. Participating builders tracked incremental costs for MCS construction. The results were then compared against similar monitoring of a control group of homes.

Bonneville Power started the second program, the Residential Construction Demonstration Project (RCDP), in 1986. Implemented by state energy offices in Idaho, Montana, Oregon and Washington, the Construction Demonstration Project is an ongoing program that serves as the laboratory for MCS development. In the first phase of the program, 158 homes were monitored. Separate meters measured power consumption for space heating and water heating. Indoor and outdoor temperatures were monitored. Operating efficiencies for heat recovery ventilators were also monitored. Empirical data then formed the basis for technical specifications in the Super Good Cents Program (by now, it was known as the Northwest Energy Code). Despite these efforts, however, the rate of adoption remained slow (Hee 1993, p.26). Regulation became the next alternative.

WASHINGTON STATE LEGISLATES 'MCS' INTO THE BUILDING CODE

Washington State had moved at the outset of the Power Act to adopt MCS into its building code. In 1986, many features of MCS formed the basis for the 1986 Washington State Energy Code. The 1986 Code allowed for flexibility in building design. Conservation standards of building elements could be modified so long as equivalent space heating performance for the building was maintained[2]. Different standards were established for houses in the moderate coastal climate (Climate Zone 1), and in the colder interior climate (Climate Zone 2).

The 1986 Code acted as a minimum building standard for electrically heated houses. Enforced throughout Washington State, the 1986 Code achieved up to 60 percent of the electric savings predicted for MCS.

On July 1, 1991, the State of Washington adopted the latest version of its energy code. Compliance can be achieved in one of three ways (WSEC 1991, p. 1):

1) Compliance according to a pre-established "energy budget":
   - Where non-renewable forms of energy are used (i.e. natural gas or oil), proposed buildings must not exceed the energy budget of a similar building built to conservation standards.

- The analysis includes parameters such as climate, physical building data (size, shape, mass, etc.), operational data (set point temperature, humidity, lighting, etc.), mechanical efficiencies, and building loads (heat gain from internal sources).
- This option is considered flexible because it does not restrict the builder's choice of methods and materials.

2) Compliance by building components analysis:
   - Permits trading off insulation values among different building components. Compliance is achieved so long as the overall standard for the structure is not exceeded.
   - This option is also considered flexible because it does not restrict the builder's choice of methods and materials.

3) Compliance to prescribed standards for each component:
   - Prescribes minimum insulation values major building components.
   - Standards are sensitive to climate conditions, and fuel type. For instance, a set of standards exists for,

     i. electrically heated buildings in coastal Washington (zone 1);

     ii. electrically heated buildings in the rest of Washington (zone 2);

     iii. natural gas heated buildings in zone 1; and,

     iv. natural gas heated buildings in zone 2.
   - In each set of standards (i.e. 'i' to 'iv' above), insulation values for major building components are combined in up to eight different "packages". Exhibit 3.1 illustrates three of the eight packages prescribed for electrically heated houses in zone 1.

Exhibit 3.1 Prescriptive requirements – prescribed by the 1991 *WSEC.*

	Component insulation values for three "component packages" (h·ft²·°F/Btu)[1]		
	I	II	IV
Glazing % of floor area	10	12	15
Glazing R-value	2.2	2.3	2.5
Doors R-value	2.5	5	5
Ceilings other than single rafter or joist vaulted ceilings	38	38	38
Vaulted ceiling	30	30	30
Wall above grade	21	19	19
Wall below grade – insulate on exterior to R10, or on interior as listed	21	19	19
Floors over crawl spaces or exposed to ambient air conditions	30	30	30
Slab on grade	10	10	10

1 Minimum standards for electrically heated houses in zone 1. Units in "hours, square feet, degrees Fahrenheit per Btu".

Source: *WSEC* 1991, p. 67.

The 1991 Code applies to all buildings where human occupancy takes place. This includes portions of buildings such as factories and warehouses. Whereas the 1986 Code applied to electrically heated buildings, the 1991 Code encompasses different energy sources including natural gas, and electricity.

ECONOMIC ANALYSIS OF THE 1986 AND 1991 ENERGY CODES BY THE WSEO

The Washington State Energy Office (WSEO) recently published findings of the University of Washington's cost-benefit analysis of the 1986 Washington State Energy Code[3]. The study (WSEO, 1989) compared the costs of using building code measures to save electricity and natural gas, and the benefits received in avoided costs for new electricity supply. The discount rate used was 3 percent (real). Houses and insulation were assumed to last 70 years. Maintenance costs for windows were estimated to be 10 percent of their original cost every 5 years.

The study presented its findings in terms of "levelized costs". Levelized costing is a means of converting capital costs into an annual equivalent. It requires specification of a discount rate and life of an asset[4]. When savings are normalized per unit of energy, this permits a comparison with analogous levelized costs[5] of supplying energy.

Exhibit 3.2 presents the study's findings. Levelized costs for electricity conservation ranged from 2.0 to 2.1 cents per kilowatt-hour. This compares with the estimate for new electricity resources, 5.5 cents per kilowatt-hour.

Natural gas heated homes provided slightly different problems. The study noted that "standard published estimates of the long term marginal cost of new natural gas resources [were not available]" (WSEO 1989, p. 4-13). An accurate surrogate price was described as, "the wholesale rate at which Washington utilities [purchased natural gas] from the Northwest Pipeline Company" (WSEO 1989, p. 4-14). The same discount rate, time period, and window replacement cost assumptions were used as in the calculation for marginal electricity resource costs. The findings established the 1986 Code as net beneficial relative to purchasing natural gas.

Exhibit 3.2 Levelized Costs of Energy Conserved and Incremental Production, by energy source. Figures in constant 1989 US dollars.

ELECTRICITY (costs per kilowatt-hour, US¢/kWh)		
Coastal Washington	Interior Washington	Cost for new electricity resources
3.0 (1986 Code) 2.1 (1991 Code)	2.2 (1986 Code) 2.0 (1991 Code)	5.5
NATURAL GAS (costs per kilowatt-hour, US¢/kWh)		
Coastal Washington	Interior Washington	Cost for new natural gas supply
1.02 (1986 Code) 1.60 (1991 Code)	0.78 (1986 Code) 1.81 (1991 Code)	1.07 – no escalation rate 1.62 – escalation rate, 1.6% 3.68 – escalation rate, 4.2%

Levelized costs for natural gas were published in "dollars per million Btu". To convert to "cents per kilowatt-hour", multiply published figures by 0.342.

Source: WSEO 1989, chapter 4, pp. 13 and 14.

CONSIDER THE ENVIRONMENT – The full cost of energy generation also involves environmental impacts. Such impacts include changes to climates possibly resulting from CO_2 emissions produced in the burning of natural gas and fossil fuels, and air pollution resulting from noxious gases released in the burning of fossil fuels. In arriving at the levelized cost of new natural gas supplies, the study noted that benefits of avoided environmental damage were not included. Money saved through energy conservation would further produce a low cost, and beneficial by-product (R. Byers, 1989)[6]. Levelized costs for conserving natural gas should be lower than shown in exhibit 3.2.

In summary, conservation measures have been shown to cost less than new sources of electricity and natural gas at reasonably low discount rates. In spite of information and incentives programs designed to increase awareness of conservation measures, consumers have generally discounted long term benefits of energy-conserving homes at unreasonably high discount rates. The rate of adoption of such homes has been disappointingly slow. Concerned advocates of conservation standards have turned to regulation measures. In response to this, the State of Washington has legislated the 1986 Energy Code, and subsequently the 1991 upgraded code.

3.2 CONSERVATION PROGRAMS IN BRITISH COLUMBIA

In B.C., conservation efforts have focussed on developing standards for better insulated houses. In the late 1980s, B.C. Hydro introduced "Quality-Plus Homes". About the same time, the federal Department of Energy, Mines and Resources introduced a nation-wide program known as "R2000". Both programs involved elements of research to determine standards, demonstration to expose buyers and builders to energy-conserving houses, and certification to distinguish between such houses and conventionally built ones. Whereas Quality Plus was also useful in renovating existing houses, R2000's approach to upgrading an entire house made it more applicable to new houses.

Consumer adoption of R2000 houses has, however, been slow. About 6,000 homes have been registered as R2000 homes. This compares with over 150,000 new houses built every year in Canada (Hee 1993, p. 21). One reason for this might be the added cost of construction. One estimate puts the construction cost of building an R2000 house at about 5 percent higher than a conventional house (Richards as referenced in Hee 1993, p.22). Another reason might be the lack of consumer recognition. Little attention has been paid to educating consumers, and builders, about the benefits of energy savings received from R2000 construction. Recently, Energy, Mines and Resources has allied itself with the Canadian Home Builders Association, a nationally recognized bank, and different utilities, to develop marketing initiatives aimed at gaining wider acceptance of R2000 houses.

However, maximizing market share may not be the only purpose of the R2000 program. It can be looked upon instead as a "leading edge standard". Standards in R2000 are meant to lead industry, and the development of new building codes[7].To this extent, R2000's success can be measured in terms of the numbers of copies, or near copies, in the market. The Canadian Home Builders Association estimates that eight R2000 "clones" are built for every registered R2000 house (Hee 1993, pp. 21-2). This would mean that over 50,000 registered and unregistered R2000 houses have been built.

PROPOSED ENERGY STANDARDS FOR B.C.

Regardless of whether R2000 was or was not successful in upgrading energy standards in housing, conservation advocates in B.C. saw regulation as the most effective means to reduce space heating energy requirements. In 1993, a committee charged with recommending energy standards for the B.C. Building Code sent its draft final report to the B.C. Building Standards Branch, the government body that establishes construction standards (Ministry of Housing 1993).

The report recommended changes to the building code in order to include energy conservation standards in house construction. Both climate severity and heating fuel are considered in the insulation specifications. The report prescribed insulation levels and air tightness levels to achieve a target space heat performance. Exhibit 3.3 summarizes the report's findings.

Exhibit 3.3 Proposed energy standards for a revised B.C. Building Code. Figures represent insulation values ($hr \cdot ft^2 \cdot °F/Btu$) unless otherwise noted.

Building Assembly	Existing 1992 Standard	Recommended Energy Standard By Climate Zone[1, 2]	
		Up to 4500 degree days	Over 4500 degree days
Windows & skylights (where window & skylight areas do not exceed 20% of heated floor area).	2 (i.e., double-glazed)	2 (i.e., double-glazed)	2.8 (i.e., triple-glazed)
Windows & skylights (where window & skylight areas exceed 20% of heated floor area).	2 (i.e., double-glazed)	2.8 (i.e., triple-glazed)	3.6 (i.e., triple-glazed with Low-E)
Ceilings & attics	28	40	44
Cathedral ceilings & Flat roofs	28	28	28
Frame walls	12	20	22
Non-frame walls	12	12	12
Foundation walls to 2.5 feet below grade	5	12	12
Crawl space walls	5	12	12
Exposed floors	28	28	28
Unheated slabs on ground (slab edge, and slab underside up to 2 feet in from inside of exterior wall).	–	12	12
In-ground heating ducts	–	12	12
Radiant heating slab on ground	–	12	12
Edge of radiant heated slab	–	12	12
Air tightness (units in 'Air Changes per Hour')	–	4 ACH	4 ACH

1 The report categorized regions on the basis of 'Celsius degree days'. More degree days mean more days that require space heating.

2 In areas outside of Vancouver Island where degree days do not exceed 3500, one of two options are available to houses heated by natural gas: attic insulation may be R28 and walls R20; or, attics R40 and walls R14.

Source: Ministry of Housing 1993

Higher standards were established for most components. These included windows and skylights, ceilings and attics, frame (or exterior) walls, foundation walls, crawl space walls, and the slab on ground. Also included were standards for heating ducts situated below grade, and for air tightness.

The report divided the province into two climatic regions based on the number of Celsius degree days[8]. Generally, regions of less than 4500 degree days are the Lower Mainland and Vancouver Island. Standards were less stringent in these more moderate climates.

A further distinction was made for natural gas heated houses in regions outside of Vancouver Island and where degree days did not exceed 3500. The reason for the distinction (between natural gas and electricity heated houses) lay in life-cycle cost findings that showed the value of energy saved in natural gas heated houses would not compensate for reduced floor areas which result from greater wall thickness[9]. Walls insulated to R20 require two-inches greater thickness than walls insulated to R12 (i.e., two-by-six studs used instead of two-by-four). Thicker walls mean reduced floor areas which reduce market value. In recognizing this, the report established a lower insulation value for walls, R14, in conjunction with an R40 requirement for attics[10].

The report went on to study the need for ventilation standards. In cases where high efficiency houses are built, natural air infiltration may be reduced to sub-optimal levels. To maintain adequate ventilation, the report recommended a minimum ventilation rate of four air changes per hour[11] (i.e. 4 ACH).

Some conservation advocates view performance standards for ventilation as necessary in achieving conservation goals. They believe that air leakage may account for over half the lost energy in space heating[12]. In comparison, the 1991 Washington State Energy Code did not set performance standards for ventilation. Instead, detailed instructions on caulking, sealing, and weather-stripping were provided.

At this point, it would be useful to compare the Washington State Energy Code and recommendations in the draft report to the B.C. Ministry of Housing. Most new house construction in B.C. takes place in the Lower Mainland, a region close to the Washington border. Climate conditions are similar between the Lower Mainland and coastal Washington. How ambitious are the two codes at achieving energy conservation? Are the standards relatively easy to adopt? That is, how realistic are the prescribed standards? What are the costs and benefits of these standards?

A Comparison Of The 1991 WSEC And The B.C. Draft Report

The scope of the 1991 Washington State Energy Code (*WSEC*) and of the draft report to the B.C. Ministry of Housing (hence referred to as the *B.C. Report*) are different. The *B.C. Report* affects primarily new houses. Among its recommendations, however, was that standards extend to other (and possibly all) residential buildings. The *WSEC* explicitly encompassed new houses, schools, office buildings, and other new buildings and structures where people work, seek refuge, or reside. This included portions of industrial buildings designed for human occupancy. At present, it appears that the *B.C. Report* is limited in its scope of application in comparison to the *WSEC*. However, discretion rests with the (B.C.) Building Standards Branch as to how widely or narrowly the report's recommendations will apply.

The ease with which industry will adopt a new code depends on the code's "flexibility". Flexibility refers to the code's ability to accept deviations from prescribed standards so long as overall conservation objectives are met. For instance, in remote regions, high costs for transporting certain materials might make them unfeasible for use in house construction. Other materials must be used. A computer program can be used to perform an "energy audit" on the proposed building. This is known as "performance-based" compliance (in contrast to "prescription-based" compliance). Energy consumption results are then compared with, and must not exceed, results for a similar building built to prescribed standards.

The *WSEC* and the *B.C. Report* both claim to be flexible. That is, both codes permit the builder the option of building to prescribed standards for each component, or meeting performance standards for the building as a system. However, the *WSEC* goes further.

As an intermediary step between performance analysis on the building, as a system, and prescribing minimum R-values for each component, the *WSEC* provides minimum performance standards for component assemblies (a two-by-four stud is a component of the exterior wall which is an assembly). In raising the insulation value of one assembly, the *WSEC* allows another assembly's insulation value to decrease below the prescribed minimum so long as the heat loss for the building envelope (i.e., the entire system) does not exceed the total heat loss resulting from compliance to specified assembly insulation values. This is known as compliance by "component performance".

This added level of flexibility appears to be redundant because an energy audit must still be used to evaluate proposed deviations from specified insulation values. Both the *WSEC* and the *B.C. Report* effectively achieve the same degree of flexibility in allowing performance based compliance.

Different ratios of window area to floor area in a building affect space heating requirements. A code's flexibility depends partly on its ability to accommodate these differences. The *WSEC* provides up to eight combinations, or "packages", of standards depending on the percentage of window-to-floor area. Exhibit 3.1 listed three of these packages for electrically heated houses in Zone 1 (coastal Washington). It is worth noting that prescribed standards may change little between packages. For instance, in going from twelve to fifteen percent window-to-floor area, window R-value increased to 2.5 (from 2.3), but R-values for remaining components were unchanged. Nevertheless, the *WSEC* provides a set of seven or eight packages for each of the following:

1. electrically heated houses in Zone 1;
2. natural gas heated houses in Zone 1;
3. electrically heated houses in Zone 2; and,
4. natural gas heated houses in Zone 2.

As a result, the *WSEC* provides close to thirty compliance packages (4 categories multiplied by 7 or 8 packages) based on window area, climate, and fuel type.

In contrast to this, exhibit 3.3 shows that the *B.C. Report* provides two packages for coastal, and again for non-coastal, B.C. based on window-to-floor area. Natural gas heated houses are permitted lower attic or wall standards, but only in coastal regions, and only outside of Vancouver Island. The *B.C. Report* thus provides five compliance packages:

1. Coastal region, electrically heated houses where window-to-floor area does not exceed 20 percent;
2. Coastal region, electrically heated houses where window-to-floor area exceeds 20 percent;
3. Coastal region outside of Vancouver Island, natural gas heated houses;
4. Non-coastal region, electrically heated houses where window-to-floor area does not exceed 20 percent; and,
5. Non-coastal region, electrically heated houses where window-to-floor area exceeds 20 percent.

The *WSEC* and the *B.C. Report* are similar in many other ways. Both discuss alternatives for venting and heating crawl spaces. Both establish minimum air infiltration rates. In terms of economic and financial analysis, both codes analyzed standards in terms of "cost-effectiveness", and "affordability". Cost-effectiveness refers to net benefits in setting a standard. Discounted benefits from saved energy (i.e. electricity or natural gas) equal or exceed discounted capital costs of the energy-conserving upgrade. Affordability refers to a buyer's ability to meet incremental carrying costs of conservation upgrades. A recommended upgrade would be accepted if there were no significant difference from the previous standard in the buyer's ability to purchase and meet monthly carrying costs. Resulting standards in the *WSEC* and in the *B.C. Report* have met cost-effectiveness and affordability criteria (*WSEC* 1991, and Ministry of Housing 1993).

The *WSEC*, at first, appears to be more flexible than the *B.C. Report*. The *WSEC*'s thirty or so prescribed standards packages and two performance based evaluations exceed the number of options provided in the *B.C. Report*. However, it is uncertain whether extra compliance measures in the *WSEC* bring added benefits. The *WSEC* prescribes different component standards according to minor changes in window-to-floor areas. Yet, it has not been shown that significant differences in net benefits arise from making such fine distinctions. The *WSEC* permits compliance by system performance (i.e., the building as a system) and component assembly performance. However, the second option seems to be redundant – in order to trade insulation values among component assemblies, the building envelope must be analyzed as a system. Ultimately, simplicity in the *B.C. Report* may cause it to be less costly to monitor and enforce than the *WSEC*. However, it remains unclear whether any difference in flexibility exists between the *WSEC* and the *B.C. Report*.

In terms of scope, exhibit 3.4 shows the *WSEC* encompassing residential, as well as non-residential buildings. The *B.C. Report* primarily affects housing. This difference in scope results from ongoing revisions to the Washington code over several years. The Ministry of Housing report recommends that its findings should also apply to occupancies other than housing. It remains to be seen whether the scope of an ensuing B.C. Energy Code would be as widely applied as its counterpart in Washington State.

Exhibit 3.4 Comparison of the B.C. Energy Standards Report and the 1991 Washington State Energy Code.

	The B.C. Energy Standards Report	The 1991 Washington State Energy Code
SCOPE	• New houses and residential portions of mixed-use buildings. • Recommends inclusion of other buildings used for residential purposes.	• New houses, schools, offices, retail stores. • All new buildings built primarily for human occupancy including portions of factory and industrial occupancies.
FLEXIBILITY	• Compliance based on energy audit – performance based. OR • Prescribed construction standards.	• Compliance based on energy audit of entire building – performance based. OR • Compliance based on energy audit of individual component assemblies – component performance. OR • Prescribed construction standards.
PRESCRIBED STANDARDS	• Standards sensitive to climate, window-to-floor area, and fuel type. A total of 6 standards packages. • Performance based ventilation standard. • Prescribed construction standards for crawl spaces. • Standards selected on basis of flexibility, cost-effectiveness and affordability.	• Standards sensitive to climate, window-to-floor area, and fuel type. Over 30 standards packages. • Prescribed construction standards to reduce air leakage. • Prescribed construction standards for crawl spaces. • Standards selected on basis of flexibility, cost-effectiveness and affordability.

Sources: Ministry of Housing report 1993; WSEC 1991.

3.3 BEYOND MINIMUM STANDARDS IN B.C.

What benefits arise from recommendations in the *B.C. Report*? The answers come as indirect results of a recently published B.C. Hydro (1993b) study referred to as the *Electricity Conservation Potential Review* (hence referred to as the *Review*).

The *Review* examines the possible size and scope of electricity conservation in B.C. Electricity used in residential space heating was one of the categories examined. Using energy auditing software[13], the *Review* analyzed space heating loads resulting from upgrades to conventional houses (therein referred to as 'standard houses'). First, the analysis looked at upgrading conventional houses to R2000 levels. Second, it looked at upgrading conventional houses to "Advanced Houses" levels.

Advanced Houses is a research and demonstration program started in 1991 by Energy, Mines, and Resources Canada (EMR). The Advanced Houses program incorporates innovative technologies in space heating, domestic hot water equipment, appliance use, and lighting, in order to reduce overall energy consumption a further 50 percent below R2000 targets.

Conservation standards in the *B.C. Report* (Ministry of Housing 1993) fall between R2000 levels and Advanced Houses levels. Most of the *B.C. Report*'s envelope standards equal or exceed R2000 standards. Results from the *Review*'s (B.C. Hydro 1991) research into construction upgrades therefore provide an approximation to proposed standards in the *B.C. Report* (albeit for electricity only). Exhibit 3.5 shows that incremental annual savings as a result of upgrading to R2000 levels would be 12,833 kilowatt-hours in the Lower Mainland, 10,908 kilowatt-hours on Vancouver Island, and 16,222 kilowatt-hours in the Interior region of B.C. Additional savings are realized in upgrading to Advanced Houses levels.

In determining economic costs and benefits from upgrades, the *Review* looked at the "total resource cost" (i.e., levelized cost) for each upgrade. An upgrade is net beneficial if its levelized cost is less than the long run marginal cost of electricity which was established in the *Review* as 6.3 cents per kilowatt-hour. Exhibit 3.5 shows that upgrades to R2000 levels are beneficial (using a real discount rate of 8%) in all regions of B.C. Upgrades to Advanced Houses levels are not beneficial on Vancouver Island. A discount rate sensitivity analysis confirms R2000 upgrades as beneficial under 4, 8, and 12 percent real rates. Advanced Houses upgrades are beneficial on Vancouver Island only when using a 4 percent real rate; in the Lower Mainland using 4 and 8 percent rates, and in the Interior using 4, 8, and 12 percent rates.

Exhibit 3.5 Levelized cost (LC) of electricity saved from upgrading to R2000 and Advanced Houses levels.[1]

	Lower Mainland	Vancouver Island	B.C. Interior Regions
STANDARD CONSTRUCTION VS R2000			
Savings per house (kWh/yr)	12,833	10,908	16,222
Cost (1991 dollars)	$5,201	$5,201	$5,839
LC @ 8% discount rate (¢/kWh)	3.6	4.2	3.2
LC @ 12% disc. rate (¢/kWh)	5.0	5.9	4.5
LC @ 4% disc. rate (¢/kWh)	2.3	2.8	2.1
STANDARD CONSTRUCTION VS. ADVANCED HOUSES			
Savings per house (kWh/yr)	15,389	13,081	18,278
Cost (1991 dollars)	$9,810	$9,810	$8,952
LC @ 8% discount rate (¢/kWh)	5.7	6.7	4.4
LC @ 12% disc. rate (¢/kWh)	7.9	9.3	6.1
LC @ 4% disc. rate (¢/kWh)	3.7	4.3	2.8
LONG RUN MARGINAL COST OF ELECTRICITY (¢/kWh)	6.3	6.3	6.3

1 Results reproduced for the category 'New, Single-detached Houses'. Figures given in 1991 cents per kilowatt-hour (¢/kWh).

Source: B.C. Hydro 1993b, p. 130c.

The implication for the Technical Advisory Committee's proposed standards is that, for electrically heated new houses, it would be beneficial to adopt such standards. It remains to be seen whether similar benefits will accrue to houses heated using other fuels, especially natural gas. Presently, B.C. Gas (one of B.C.'s private gas utilities) is studying energy use behaviour in natural gas heated homes. From this, the gas utility hopes to determine the potential for natural gas conservation in B.C.

3.4 SUMMARY

Energy conservation is seen by many in the energy sector as an inexpensive way to provide for future energy demand. Upgrading construction practices is one way of achieving energy conservation in housing. Consumers, however, have not been easily persuaded to the benefits of higher and more expensive construction standards. In response (or perhaps in anticipation of consumer response), conservation advocates have chosen regulation as the means to conserve space heating energy. In Washington State, conservation standards were put into law via the 1991 Washington State Energy Code. In B.C., the Building Standards Branch is considering similar conservation standards for future Building Code revisions (Ministry of Housing 1993).

Can it be shown that, in the face of such efforts to regulate conservation standards, benefits arising out of upgraded building codes will be positive? To date, the answer is 'yes'. That is, cost-effectiveness studies have been done, and shown to be net beneficial, for all proposed standards. In addition, support for such standards can be found in the *Electricity Conservation Potential Review* (B.C. Hydro 1993b). Under discount rate sensitivity (and environmental credits, too), proposed standards yielded net benefits. However, studies to date have not shown the effects of different supplier costs. Costs of upgrades will change as regulation changes consumer choices. How robust are the benefits from conservation standards in the face of changing capital and operating costs? Answers to this question can be found in chapter 4, and will contribute to what would be appropriate upgrades.

FOOTNOTES

1 Schwartz as referenced by Hee, 1993.

FOOTNOTES ...

[2] This was accomplished using the energy simulation software program, SUNDAY®.

[3] The 1991 Code was in draft form at the time.

[4] In comparison, net present value converts capital costs and benefits into a present day equivalent. Similar to levelized costs, net present value also requires specification of a discount rate and life of an asset.

[5] Other studies have referred to levelized costs as "annualized costs", or "total resource costs". The second term was used in B.C. Hydro's Conservation Potential Review (B.C. Hydro 1991).

[6] Byers suggested an avoided cost for environmental damage be 83 cents (US) per million-Btu.

[7] Lougheed as referenced in Hee 1993, p.22

[8] Degree days, in the case of heating, denote the number of days where the average outdoor temperature is lower than an established standard, or design temperature. Depending on the accepted unit of measure used in recording temperature, either Celsius or Fahrenheit degree days may be used.

[9] In conversation with a principal at Sheltair Scientific, a contributer to the Ministry of Housing report.

[10] However, R14 insulation techniques are presently seldom used in construction. Some industry experts believe that, because R14 insulation techniques are presently not widely used, the final cost of upgrading walls to R14 might be higher than originally thought.

[11] One air change per hour means that the volume of outdoor air introduced into a house in a one hour period is equal to the volume of the house.

[12] This was mentioned in conversations with experts in indoor air quality.

[13] Specifically, 'HOT2000' was used to model space heating energy consumption.

CHAPTER 4 - METHODOLOGY

The benefits of higher construction standards in housing is straightforward: higher standards reduce heat loss thus reducing energy consumption. Reduced energy consumption translates into avoided costs of providing new energy supply.

However, higher standards may mean overall higher costs for housing construction. Richards (Hee 1993, p.22) suggests that an R2000 house costs about 5 percent more to construct than a conventionally built house. Higher housing costs mean overall fewer houses demanded. Those houses that will be built will require products developed for energy-conserving housing. Demand for these products will increase thus reducing their cost relative to other products. In addition, rapidly changing technology in energy conservation (i.e. windows, heating systems, etc.) will also affect costs. The total cost of building to higher standards is uncertain, which suggests that a range of supplier costs should be used in analyzing net benefits of housing upgrades.

In this chapter, the method of analysis is presented and discussed. Cost-benefit analysis will be used to evaluate upgraded construction standards. In order to do this, impacts of raising construction standards first must be monetized. The following impacts are considered:

- social costs of imposing new standards; and,
- social benefits from reducing the amount of energy required for space heating.

Section one of this chapter outlines the methodology used in determining space heating loads. This includes selection of houses for analysis, and selection of building components for upgrading. Sections two and three discuss how costs and benefits for these upgrades were determined.

Finally, section four looks at the range of costs and benefits that, in reality, might arise, and thus provides the framework for sensitivity analysis.

4.1 SETTING THE PARAMETERS FOR ANALYSIS

SELECTING HOUSES FOR ANALYSIS

The study calculated heating requirements for a sample of Vancouver area houses. Initially, twenty home owners were approached to participate in the study. Of the eleven that took part, only three lived in houses built to conventional standards (see appendix A for a definition of conventional standards). The remaining eight lived in townhouse units built to R2000 standards[1]. It was decided to include one of these units in the upgrades analysis to estimate net benefits of different window technologies.

The computer program HOT2000, version 6.02, was used to calculate heating loads for each house. HOT2000 estimates space and water heating loads in single family residences[2]. To test the accuracy of HOT2000, the eleven houses were analyzed, and results were compared with actual energy consumption data.

Calculated results differed from actual energy consumption by 77 percent (on average). For the three conventionally built houses, the average error was 93 percent. Martin (1983) compared actual heating loads of R2000 homes with HOT2000 estimates, and found that 20 percent was an acceptable error in predicting space heating energy consumption. However, this was not a useful parameter for selection in the current study for two reasons:

1. Houses intended for upgrade analysis were to be conventionally built. Parameters for these houses, such as natural air leakage and effective insulation values, are more difficult to determine than for R2000 houses.

2. A statistically significant sample was not available. Three houses were conventionally built, and eight were built to R2000 standards.

Appendix C presents findings for the validation test. Factors that may have prevented more accurate HOT2000 estimates include the following:

- Accurate records of indoor set point temperatures were not available. A one degree (Celsius) change in the indoor average temperature can result in greater than a 10 percent change in heating load[3].
- Electricity consumption for heating was not separated from other electrical uses.
- Most of the occupants frequently used fireplaces. Occupants of the three conventionally built houses used their fireplaces several times each week. Since HOT2000 does not simulate the effects of fireplace use on space heating[4], frequent fireplace use will increase the error of HOT2000 estimates.

It was decided to select two of the three conventionally built houses on the basis of foundation type. One off the two "slab-on-grade foundation" houses was selected in addition to the "crawl space foundation" house.

Upgrades To Conventional Methods

In designing a set of upgrades, or energy-conserving measures, for analysis, a team of industry experts was consulted. In addition, trade journals were used as reference in selecting measures for analysis.

Three key strategies distinguish the thermal performance of energy-conserving houses from conventionally built houses:

- the proportion of windows (i.e. glazing) facing south;
- the insulation value of the house's opaque (i.e. no glazing) envelope; and
- the degree of air infiltration through the opaque envelope (Dumont et al. 1983; WSEO 1989).

Windows that face south can take advantage of passive solar heat gain[5]. In new house construction, roughly 75 percent of the total window area will face south. However, conventionally built houses will generally not be made of sufficient mass to store the heat from insolation. Consequently, localized over-heating will occur, even in winter months, which must be relieved by either opening a window or closing a shutter, and thus negating any heat gain effects. It is generally accepted that, for conventionally built houses, window area not exceed 6 percent of the total floor area (Dumont et al. 1983).

Increasing the insulation value of the opaque envelope is a significant strategy in energy-conserving housing. Higher insulation values reduce the rate of heat conducted through framing members, foundations, windows and doors. Typically, insulation for framing members and foundations comes in fiberglass batts, loose blown-in cellulose, and rigid foam boards. Window frames and door frames can be provided with thermal bridging that serves to interrupt the flow of heat from interior to exterior surfaces.

Air infiltration can be significantly reduced – primarily by means of a vapour barrier. A vapour barrier can reduce air infiltration by up to 58 percent (Dumont 1983). One method commonly used in reducing air infiltration is referred to as "6-mil poly". With this technique, a thin sheet of plastic is used in walls and ceilings to form a continuous barrier between the interior and the exterior of a house. However, holes must be created in a vapour barrier for services such as electrical outlets and plumbing. When left unsealed, these holes render the vapour barrier ineffective.

Another technique for reducing infiltration is known as "advanced drywall approach", or ADA. In ADA, all joists and headers are individually sealed, which, when combined with a vapour barrier in walls and ceilings, provides a more reliable barrier to air infiltration than 6-mil poly.

The virtual elimination of natural air infiltration creates a new problem – poor air quality. This problem can be alleviated with the installation of mechanical ventilation. One means of mechanically ventilation is a heat-recovery ventilator (HRV). The HRV ventilates, exhausts stale indoor air, and reduces the amount of energy required in heating outdoor air.

EXPERTS ADVISORY TEAM

Component analysis yields a multitude of options worthy of investigation. In order to limit the analysis to readily available alternatives, specific components were suggested for analysis by a team of advisors. This "focus group" offered expertise in areas of architecture, building sciences, general contracting, and property development. Each member was individually interviewed and asked to comment on at least three aspects of house design that s/he considered both effective in conserving energy and readily available for industry adoption. Follow-up interviews were used to verify construction techniques used in each component upgrade.

The results of the interviews are presented in exhibit 4.1A. Five strategies for energy conservation were addressed:

1. Increase southern exposure of windows and other glazing;
2. Increase insulation value of the building envelope;
3. Reduce natural air infiltration;
4. Increase heating system efficiency; and,
5. Increase consumer awareness of long term benefits of conservation.

Of the five strategies, increasing south glazing was paid little attention. It was felt that increased southern exposure would only lead to over-heating since common building practices do not provide sufficient mass (i.e. granite floors instead of wood) to adequately store the heat in south-exposed areas of a house[6].

During interviews, two more strategies arose: efficiency of space heating systems, and industry attitudes toward energy conservation. Changing attitudes is in effect a call to address market failures such as information asymmetry and myopia discussed in chapter 2. Attitudes are, however, beyond the scope of a HOT2000 analysis.

Since HOT2000 can model several types of heating systems, it was decided that gas furnaces and electric resistance heaters would also be analyzed[7]. In this way too, costs and benefits of "fuel switching" can be analyzed. Of the strategies provided in exhibit 4.1A, three were within the scope of this study: envelope upgrades; air infiltration improvements; and efficiencies of space heating systems (which included fuel-switching). Exhibits 4.1B summarize the energy-conserving measures used in this study.

Exhibit 4.1A Summary of responses from the Experts Advisory Team – categorized by the respondent's profession.

STRATEGIES FOR ENERGY CONSERVATION	Architect	Buildings Sciences Engineer (3 surveyed)	General Contractor (2 surveyed)	Property Developer	Total votes
A. SOUTH EXPOSURE		√			1
B. ENVELOPE UPGRADE					
1. Wall R-value upgrade to R20 or more.	√	√√	√√	√	6
2. Attic insulation upgrade to R40 or more.	√	√	√√	√	5
3. Upgrade window R-value.	√	√√		√	4
4. Insulate under slab.	√	√	√	√	4
C. AIR INFILTRATION Install HRV and use air-tight construction.		√√√		√	4
D. SPACE HEATING SYSTEMS					
1. Upgrade gas furnace efficiency	√	√√	√		4
2. Use electric baseboard heat only		√	√	√	3
3. Use heat pump		√			1
E. CHANGE ATTITUDES RE: CONSERVATION		√√√	√		4

Exhibit 4.1B Details of each Energy-Conserving Measure (ECM).

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM00	n.a.	Existing house parameters (refer to appendix U).
ECM11	20	Walls from R12 to R20 using 2X6 wood stud construction.
	4.5	Doors from R3.6 to R4.5 using insulated doors.
		Cost of reduced floor area
ECM12	40	Walls from R12 to R40 standard using 2X6 and double studded wall construction.
	8	Doors from R3.6 to R8 using insulated doors.
		Cost of reduced floor area
ECM21	40	Attics & floor overhangs from R28 to R40 using blown-in cellulose insulation.
ECM22	8.5	Place 2-inch rigid insulation under slab including perimeter.
	8.5	Insulate slab edge – assume a .3 meter width of rigid insulation.
ECM23	6	Blown-in cellulose on all interior surfaces of basements & crawl spaces (and glue compound).
ECM31		Replace existing windows with double-glazed (DG) windows and thermally-bridged aluminum (TB) frames.
ECM32		Replace existing windows with DG windows and vinyl frames.
ECM33		Replace existing windows with DG windows and argon air space, and TB frames.
ECM34		Replace existing windows with triple-glazed windows and TB frames.
ECM35		Replace existing windows with DG windows and low-e film, and vinyl frames (e = 0.2).
ECM36		Replace existing windows with DG window and low-e film, insulated spacer, and TB frames (a.k.a. Heat Mirror® 66'

DG: double-glazed windows.
TB: thermally-bridged aluminum frames.

Exhibit 4.1B Details of each Energy-Conserving Measure (ECM).

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM41		Employ air-tight construction (Advanced Drywall Approach). Heat recovery ventilator. Add 0.8 kWh/day to Base Loads as estimate of half-year operation of HRV.
ECM51		Replace existing heating system with a natural gas furnace of efficiency 78 percent. Decrease capacity from 75MBTU to 60MBTU.
ECM52		Replace existing heating system with a natural gas condenser furnace of steady-state efficiency 94 percent. Decrease capacity from 75MBTU to 40MBTU.
ECM53		SWITCH FUEL SOURCE TO ELECTRICITY - Replace existing heating system with electric radiant baseboard heaters of effective efficiency 100 percent. Do not change Base Loads 2.4 kWh/day figure. Subtract original cost of a 78%-eff. gas furnace. Benefit of re-acquired floor area
		INTEGRATED UPGRADES -
ECM95		Combine ECMs 11, 21, 22, 41, 52. Fuel source: NATURAL GAS.
ECM96		Combine ECMs 11, 21, 22, 41, 53 (as per R2000 house). Fuel source: ELECTRICITY.

HRV: heat recovery ventilator.
kWh: kilowatt-hours.
MBTU: 1000 British Thermal Units.

4.2 DETERMINING COSTS OF UPGRADING

THE INCREMENTAL COST OF UPGRADING

The cost of raising housing standards consists of at least two components: the incremental cost of each upgrade, and the value of lost or gained floor area resulting from the upgrade. One method of determining upgrade costs is to refer to trade journals that publish costs for materials and labour. Costs for construction of building components are provided as a national average. Formulae are given, and can be used to calculate regional, and local, costs. However, focus group discussions showed that this method did not represent actual costs adequately. Costs for materials will change. The actual amount of labour required in performing a task frequently differs from published figures. In the opinion of the two contractors in our focus group, "[We] threw away the book right after leaving school." It appeared that published cost estimates did not reflect current construction costs.

A second method of determining upgrade costs, and the one used in this study, is to ask the people who supply the goods and services. Interviews were conducted with contractors and suppliers, and resulting costs were then used to value each energy conserving measure (ECM). Exhibits 4.2A summarize the resulting unit costs[8]. The interviews involved the following steps:

1. Identifying costs relevant to each ECM. Direct taxes such as provincial sales tax, and the goods and services tax were not included, nor were income taxes.
2. In each case, at least two contractors or suppliers were asked to estimate the difference in cost to supply and install each ECM. Window suppliers were asked to price a list of window sizes specific to each house.

3. Unit costs were calculated for each ECM, i.e. dollars per square foot ($/sf) for wall, ceiling, and floor insulation; watts per square foot (W/sf) for electric baseboard heaters; the system costs for furnaces and HRVs; and installed costs for windows. Where responses differed by greater than 20 percent, discretion was used in weighting the "outliers". This involved phoning the original suppliers and clarifying the scope of work to be priced. If subsequent values still did not converge, an average was taken.
4. Differential unit costs were then applied to the houses in the study. Window upgrade costs were determined by replacing each existing window with an upgraded window of the same size.

Exhibit 4.2A Summary of unit costs for component upgrades.

ECM	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION	CHANGE IN UNIT COST ($)		
ECM00	Existing house parameters (refer to appendix U).			
ECM11	Walls from R12 to R20 using 2X6 wood stud construction.	$0.35	per	sq ft wall
	Doors from R3.6 to R4.5 using insulated doors.	$1.25	per	sq ft door
	Cost of reduced floor area	$50.00	per	lost sq ft
ECM12	Walls from R12 to R40 standard using 2X6 and double studded wall construction.	$1.37	per	sq ft wall
	Doors from R3.6 to R8 using insulated doors.	$1.86	per	sq ft door
	Cost of reduced floor area	$50.00	per	lost sq ft
ECM21	Attics & floor overhangs from R28 to R40 using blown-in cellulose insulation.	$0.23	per	sq ft attic or floor overhang
ECM22	Place 2-inch rigid insulation under slab including perimeter.	$0.50	per	sq ft footprint
	Insulate slab edge – assume a .3 meter (1 foot) width of rigid insulation.	$0.50	per	sq ft
ECM23	Blown-in cellulose on all interior surfaces of basements & crawl spaces (and glue compound).	$0.23	per	sq ft wall & footprint area
ECM31	Replace existing windows with double-glazed (DG) windows and thermally-bridged aluminum (TB) frames.	per house basis		
ECM32	Replace existing windows with DG windows and vinyl frames.	per house basis		
ECM33	Replace existing windows with DG windows and argon air space, and TB frames.	per house basis		
ECM34	Replace existing windows with triple-glazed windows and TB frames.	per house basis		
ECM35	Replace existing windows with DG windows and low-e film, and vinyl frames (e = 0.2).	per house basis		
ECM36	Replace existing windows with DG window and low-e film, insulated spacer, and TB frames (a.k.a. Heat Mirror® 66)	per house basis		

DG: double-glazed windows.
TB: thermally-bridged aluminum frames.

Exhibit 4.2A Summary of unit costs for component upgrades.

ECM	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION	CHANGE IN UNIT COST ($)		
ECM41	Employ air-tight construction (Advanced Drywall Approach).	$0.71	per	sq ft walls
		$0.75	per	sq ft attic
	Heat recovery ventilator.	per house basis		
	Add 0.8 kWh/day to Base Loads as estimate of half-year operation of HRV.			
ECM51	Replace existing heating system with a natural gas furnace of efficiency 78 percent. Decrease capacity from 75MBTU to 60MBTU.	per house basis		
ECM52	Replace existing heating system with a natural gas condenser furnace of steady-state efficiency 94 percent. Decrease capacity from 75MBTU to 40MBTU.	per house basis		
ECM53	Replace existing heating system with electric radiant baseboard heaters of effective efficiency 100 percent. Do not change Base Loads 2.4 kWh/day figure.	$0.50	per	sq ft floor area
	Subtract original cost of a 78%-eff. gas furnace.	per house basis		
	Benefit of re-acquired floor area	$50.00	per	re-gained sq ft
	INTEGRATED UPGRADES -			
ECM95	Combine ECMs 11, 21, 22, 41, 52.	per house basis		
ECM96	Combine ECMs 11, 21, 22, 41, 53 (as per R2000 house).	per house basis		
	Fuel source: ELECTRICITY.			

HRV: heat recovery ventilator.
kWh: kilowatt-hours.
MBTU: 1000 British Thermal Units.

THE COST OF ALTERED FLOOR AREAS

Some upgrade measures will reduce, or increase, the total floor area in a house. Where wall depth is increased by replacing conventional two-by-four studs with two-by-six studs (in actual dimensions, the change is from a 3.5 inch width to a 5.5 inch width), the net reduction in area in relation to total length (i.e. perimeter) of exterior wall turns out to be "0.167 square feet per lineal foot" (see the example 1 below).

Example 1:

$$\text{Net Reduction In Floor Area Per Lineal Foot of Wall} = 1 \text{ linear foot} \times \frac{5.5 \text{ inches} - 3.5 \text{ inches}}{12 \text{ in. per ft.}} = 0.167 \text{ square feet}$$

For a two-level house of exterior dimensions 33 feet by 27 feet, this results in a change from 1,782 square feet originally to 1,742 square feet (see example 2 below).

In establishing the value of such a change, the problem arises whether to measure lost (or gained) floor area by construction cost, or by market value. Market value was chosen because it best represented the cost to home buyers for higher housing standards. Realtors use market valuation, and generally employ the following figures[9]:

- $25 per square foot for utility space (i.e. storage and furnace rooms);
- $50 per square foot for functional living space (i.e. bedrooms, studies, washrooms); and
- $75 per square foot for general living space (i.e. dens, living rooms, recreation rooms).

In this study, $50 per square foot was selected. In example 2, the reduction in floor area of 40 square feet would result in a $2000 decrease in house value.

Example 2:

- 1,782 sq. ft. = 2 levels x 33 feet x 27 feet; Floor area using 2 x 4 studs.
- 1,742 sq. ft. = 1,782 sq. ft. – $\frac{0.167 \text{ sq. ft.}}{\text{lineal foot}}$ x 2 levels x { 33 feet x 2 + 27 feet x 2 };

  Floor area using 2 x 6 studs.
- TOTAL REDUCTION TO FLOOR AREA = 1,782 – 1,742 = 40 square feet
- TOTAL COST OF REDUCED FLOOR AREA = $50 x 40 s.f. = $2,000

In addition to upgrades affecting wall thickness, the choice of heating system also affects floor area. In choosing electric baseboard heating, the overall floor area increases by the re-acquisition of space set aside for a furnace enclosure (typically, 12 square feet or more). The value of this increased floor area amounts to more than $600.

The value of altered floor area may significantly affect net benefits of certain upgrades. Were such values based on fixed interior dimensions (i.e., thicker walls resulting in larger exterior dimensions), then conservation standards would impinge less on net benefits. Nevertheless, current practice requires estimates based on fixed exterior dimensions.

4.3 BENEFITS OF UPGRADED HOUSING STANDARDS

THE COST FOR NEW ELECTRICITY SUPPLY

Conserving electricity, and energy in general, delays the timing of new electricity supply, and yields benefits in the form of avoided costs. The relevant avoided cost of new electricity supply is that of firm, or uninterruptible, electricity. B.C. Hydro determined that new firm electricity would cost 5.3 cents per kilowatt-hour (Cost of New Electricity Supply 1993, p. 8)[10]. In addition to firm electricity cost, the cost to expand transmission facilities must be considered. In the same report, the transmission cost for delivery to the Lower Mainland was estimated at 0.4 cents per kilowatt-hour[11]. In analyzing construction upgrades, the avoided cost used for new electricity supply will be 5.7 cents per kilowatt-hour (refer to exhibit 4.3A).

Exhibit 4.3A Cost of New Electricity Supply to the Lower Mainland.

REFERENCE	Base Year	Costs per kilowatt-hour
Cost Of New Electricity Supply – 1993; (B.C. Hydro)	1992	5.3¢ firm 0.4¢ transmission 5.7¢ total

THE COST FOR NEW NATURAL GAS SUPPLY

In the case of natural gas, avoided cost is measured by the savings from not having to purchase and supply incremental gas. One approach to determining avoided cost is to use the marginal cost of the next supply increment. In its "Gas Supply Optimization Model", B.C. Gas (1992) has identified this increment to be the construction of a second storage facility for liquid natural gas (LNG). During peak winter months, the marginal cost for firm gas supply has been determined in the range from 3.15 to 3.25 cents per kilowatt-hour ($8.75 to $9.04 per gigajoule)[12]. In order to reflect the cost of gas supply at peak demand, the highest figure, 3.25 cents per kilowatt-hour, will be used in construction upgrade analysis (refer to exhibit 4.3B).

Exhibit 4.3B Cost of New Natural Gas Supply to the Lower Mainland.

REFERENCE	Base Year	Costs per kilowatt-hour
Least Cost Integrated Resource Plan 1991 - 2001; (B.C. Gas)	1992	3.15¢ to 3.25¢
Avoided Cost adopted for analysis		3.25¢

The question of finding appropriate avoided costs for electricity and natural gas has not been answered definitively. It may never be answered. The discussion has simply provided realistic "base costs" for evaluating the benefits of conservation. Exhibit 4.3C summarizes the avoided costs. Using these base costs, this study will analyze externalities affecting the environment. This will be done by way of sensitivity analysis.

Exhibit 4.3C Avoided costs used as a 'base case' analysis for electricity, and natural gas.

Marginal Cost for hydroelectricity	Marginal Cost for firm natural gas supply
5.7 ¢/kWh	**3.25 ¢/kWh**

4.4 PARAMETERS FOR SENSITIVITY ANALYSIS

ENVIRONMENTAL COSTS – HYDROELECTRICITY

The process of generating electricity creates land-, water-, and air-related environmental impacts. Hydroelectricity requires that valleys be flooded resulting in the loss of silviculture, and disruption to wildlife and aqua culture. Thermal generation requires the burning of natural gas, which adversely affects air quality and contributes to global warming.

In recognizing the benefits of energy conservation, B.C. Hydro assigns environmental credits to projects deemed to be environmentally benign. A 15 percent credit is generally applied to the levelized cost of energy conserving projects (Hydro 1991 Update). Some environmental advocates argue that such a premium underestimates the negative impact of hydroelectricity on natural resources. Nevertheless, in the context of this study, 15 percent serves as a conservative estimate of the "social cost" of undertaking new electricity supply projects. The social cost of building a new hydroelectric dam therefore becomes 0.86 cents per kilowatt-hour (i.e., 15% of 5.7¢/kWh).

ENVIRONMENTAL COSTS – NATURAL GAS

Environmental impacts occur throughout the natural gas fuel cycle. These impacts are primarily air-related and include emissions of sulfur dioxide, nitrous oxides, carbon dioxide, and methane gas. Both methane gas and carbon dioxide are considered to contribute to "global warming" (Byers 1990; Shaffer 1991). Social costs[13] arise out of these environmental impacts, and gas utilities have increasingly moved toward incorporating these costs into their resource decisions.

Many jurisdictions determine social costs as the cost of controlling air emissions. One approach uses abatement costs. Here, marginal costs for pollution abatement equipment serves as a proxy for the external cost imposed by the pollutants. Three key assumptions underlie the abatement cost methodology:

1. Regulation of acceptable emission levels reflect society's preference for pollution control;
2. The marginal costs of abatement are known; and,
3. Abatement costs are distinct and attributable to the specific pollutant.

All three points can be difficult to determine. Consequently, abatement costs may bear little or no relation to actual external costs.

A second approach for estimating external costs quantifies in economic terms the damage of air pollutants on the receiving environment. The difficulty of this technique lies in the valuation of the risks to human life, and material and crop production.

B.C. Gas adopted "damage cost" methodology in assessing the social cost of natural gas use (B.C. Gas 1991). Social costs of emissions associated with natural gas use in the Lower Mainland ranged from 0.31 to 0.41 cents per kilowatt-hour[14]. This compares with 0.86 cents per kilowatt-hour social cost of hydroelectricity.

It is difficult to argue that hydroelectricity consumption impacts on the environment twice as much as natural gas consumption (0.86 is more than double 0.41). Hydroelectricity consumption produces local impacts in lost river valleys and wildlife. Natural gas consumption impacts on air quality and global warming. For the purpose of this study, the social costs of both energy types are considered to be 0.86 cents per kilowatt-hour. Exhibit 4.4A summarizes avoided costs and social costs that will be used in analyzing benefits of construction upgrades.

Exhibit 4.4A Summary of energy costs.

Energy Cost Scenario	Electricity cost	Natural Gas cost
A) Long run avoided cost	**5.7** ¢/kWh	**3.25** ¢/kWh
Social cost	**0.86** ¢/kWh	**0.86** ¢/kWh
B) Total Avoided and Social Cost	**6.56** ¢/kWh	**4.11** ¢/kWh

CHANGING SUPPLIER COSTS

Conservation standards will create greater demand for products required in energy-conserving housing. Current costs will change. Rapidly changing technologies further contribute to uncertainty in determining supplier costs. As a result, sensitivity analysis is needed on the cost side of the cost-benefit equation. Interviews with suppliers yielded prices ~~could~~ which varied up to 30 percent in certain product categories[15]. A sensitivity range of plus and minus 30 percent will be used in analyzing supplier cost changes.

THE FUEL SWITCH OPTION

In the course of analyzing energy conservation benefits, the question arises whether natural gas or electricity provides the greater benefits in upgrading construction standards. Two energy-conserving measures (ECMs) proposed for analysis entail direct comparisons of fuel-related benefits. "ECM 53" substitutes electric baseboards in place of a natural gas furnace as the source for space heating in a conventionally built house. Likewise, "ECM 96" does the same, this time in a fully upgraded house (i.e. to R2000 standards). The question of switching fuels therefore can be addressed in the scope of this study.

AN APPROPRIATE DISCOUNT RATE AND A TIME FRAME FOR ANALYSIS

To this point, discussion has centered on monetizing the impacts of a construction standards upgrade policy. Two other parameters must be discussed before cost-benefit analysis can proceed: discount rate, and the time frame over which benefits and costs are considered. The time frame chosen for this analysis is 50 years. This provides a conservative estimate of the lifetime of a typical house – other studies use lifetimes in the order of 40 or more years (WSEO, 1991). Choosing an appropriate discount rate poses a more complex issue.

In chapter 2, the idea that there exists a range of acceptable discount rates was discussed (see "Short-Sighted Markets" in chapter 2). Briefly, society's perception of what constitutes acceptable risk is determined by investments made by governments, corporations, and, to some extent, individuals. The lower and upper bounds for this range are 3 percent (federal government long bond yields in real rates) and 12 percent (average real rate of return on common stocks from 1926 to 1982). This study adopts 8 percent (about halfway between 3 and 12) for its "base case" analysis.

To most consumers though, a single discount rate does not represent reality. Energy conservation investments may be of high risk to some consumers while to others they will be seen as relatively safe. That is, the first group might not see energy savings as a good that can be traded in the housing market; the second group might possess better information about long term savings from energy conservation. Recognizing that these views exist, this study will conduct discount rate sensitivity analyses using 5 and 11 percent (real rates) as lower and upper bounds.

This range of rates still does not satisfy some in society: those who heavily discount the future, and those who consider positive discount rates as unfair to future generations. In the first group, those who exhibit discount rates greater than 25 percent effectively demand a four-year payback on investments. To answer this group, it would neither be realistic nor prudent to expect that all investments pay for themselves in a few short years. To answer the second group, a discount rate of zero would effectively find every conservation investment worthwhile[16]. It is not feasible to adopt every available investment.

As a best guess, 8 percent reflects society's overall discount rate, and a sensitivity range of plus and minus 3 percent provides acceptable "benchmarks" to analyze energy conservation alternatives. Exhibit 4.4B provides a synopsis of the range of avoided costs, opportunity costs, and discount rates adopted in this study.

Exhibit 4.4B Summary of cost scenarios for analysis.

SAVED ENERGY:	Avoided Costs			Avoided Plus Social Costs		
For electricity	5.7 ¢/kWh			6.56 ¢/kWh		
For natural gas	3.25 ¢/kWh			4.11 ¢/kWh		
DISCOUNT RATES: Applied to each analysis	5 %, 8 %, 11 %			5 %, 8 %, 11 %		
SUPPLIER COSTS:	Supplier cost quotes reduced by 30%	Supplier costs as quoted	Supplier cost quotes increased by 30%	Supplier cost quotes reduced by 30%	Supplier costs as quoted	Supplier cost quotes increased by 30%

FOOTNOTES

1 Townhouse units are attached, two or three units to a building.

2 Opinions as expressed by experts involved in designing energy-efficient housing, and engineering more energy-efficient means of space heating.

3 This was suggested while in conversation with HOT2000 users. In testing this suggestion, several heating load estimates were re-analyzed using a one degree change in setpoint temperature. Results supported the claim that HOT2000 estimates change by 10% for a one degree change in indoor temperature.

4 This was suggested while in conversation with HOT2000 users. Regular use of fireplaces that are not sealed (i.e. are not enclosed and equipped with intake and exhaust flues) will significantly change heating loads. Even if fireplaces are sealed (i.e. with glass doors), some HOT2000 experts warn that heat conduction through glass, and metal frames, may increase heating loads by 15 percent or more.

5 In the northern hemisphere.

6 This is not a general rule. Owners of custom-built houses have taken advantage of this technique.

FOOTNOTES ...

7 Heat pumps were expensive and, therefore, were not relevant to the focus of this study, namely houses built for speculation sales.

8 Details and results of the price survey can be found in appendix B.

9 Costs for floor area changes were obtained in discussions with representatives of Royal LePage Mortgage. Royal LePage Mortgage provides mortgages to home buyers.

10 Most recently, B.C. Hydro released "The Cost of New Electricity Supply in B.C. – January 1993". The 1993 report arrived at a long run marginal cost for firm electricity of 5.3 cents per kilowatt-hour (in 1992 dollars), 10 percent less than the same figure presented in the 1991 report. The cost to supply surplus energy was estimated at between 0.6 and 0.7 cents per kilowatt-hour, almost 50 percent less than the figure presented in 1991. The main reasons for the changes lie in (i), the newly adopted process of Integrated Resource Planning (IRP) which includes impacts of existing energy conservation programs, and (ii), the removal of water rental and school taxes in assessing costs for hydro projects.

11 The report stated that 35% of the cost of planned system expansion was attributable to capacity additions and 65% to energy delivery (p. 4). Energy delivery to the Lower Mainland was shown to be 0.271 cents per kilowatt-hour (p. 6). Total cost must therefore be 0.271 divided by 65%, or 0.4 cents per kilowatt-hour.

12 See table 9-1 on page 9-5 of the Integrated Resource Plan.

13 In conservation literature, social costs are also referred to as external costs, and environmental costs.

14 That is, $0.87 to $1.14/GJ. The social cost of emissions associated with thermally-generated electricity in the Lower Mainland ranged from $1.36 to $1.87/GJ.

15 For most products surveyed, at least two suppliers participated.

16 When the discount rate is zero (r=0), the present value of benefits (PV) becomes 'N' times the annual benefit 'B' (where 'N' represents number of years in the life of the asset). If the lifetime of a house were 50 years, annual savings of one dollar would be worth fifty dollars (PV = $50). In comparison, if the discount rate were 8%, these same savings would be worth just over twelve dollars (PV = $12.23). That is, a discount rate of zero overstates benefits received at the end of an asset's life and makes the initial investment decision more attractive.

CHAPTER 5 - RESULTS

Results for the cost-benefit analysis of construction upgrades are presented in this chapter. Of the three houses analyzed, two represent conventional standards of construction, and the third, conservation standards (i.e., R2000). The conventionally built houses, "H1" and "H2", are considered to be single family dwellings and "detached" from other buildings. The R2000 townhouse unit, "TH1", is also considered to be a single family dwelling. Further structural, architectural, and thermal parameters will be provided as results for each house are discussed.

Section 5.1 discusses effects of different discount rates on net savings and net costs. This is done assuming avoided costs for energy prices. Discussion is presented on a house-by-house basis. For each house, results have been categorized in the following ways:

1. *Fuel Switching* – natural gas heating has been replaced with electric baseboard heating.
2. *Heating System Upgrades* – the current operating efficiency has been upgraded with a condenser furnace, or with the addition of a heat-recovery ventilator system.
3. *Envelope and Window Upgrades* – higher insulation values have been achieved for the building envelope.

At the end of section 5.1, a summary of net benefits is provided. Avoided costs were used for energy prices. Results are presented so that net benefits of each upgrade can be compared from one house to the next.

Section 5.2 summarizes net benefits in which energy prices included both social costs and avoided costs. Results are briefly discussed and upgrade measures yielding significant changes in net benefits are noted.

For reference, the list of energy-conserving measures is provided in exhibits 5.0A. Appendix B lists details on cost calculations. Details on gigajoule savings from upgrades are provided in appendix C.

Exhibit 5.0A Details for each Energy-Conserving Measure (ECM).

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM00	n.a.	Existing house parameters (refer to appendix U).
ECM11	20	Walls from R12 to R20 using 2X6 wood stud construction.
	4.5	Doors from R3.6 to R4.5 using insulated doors. Cost of reduced floor area
ECM12	40	Walls from R12 to R40 standard using 2X6 and double studded wall construction.
	8	Doors from R3.6 to R8 using insulated doors. Cost of reduced floor area
ECM21	40	Attics & floor overhangs from R28 to R40 using blown-in cellulose insulation.
ECM22	8.5	Place 2-inch rigid insulation under slab including perimeter.
	8.5	Insulate slab edge – assume a .3 meter width of rigid insulation.
ECM23	6	Blown-in cellulose on all interior surfaces of basements & crawl spaces (and glue compound).
ECM31		Replace existing windows with double-glazed (DG) windows and thermally-bridged aluminum (TB) frames.
ECM32		Replace existing windows with DG windows and vinyl frames.
ECM33		Replace existing windows with DG windows and argon air space, and TB frames.
ECM34		Replace existing windows with triple-glazed windows and TB frames.
ECM35		Replace existing windows with DG windows and low-e film, and vinyl frames (e = 0.2).
ECM36		Replace existing windows with DG window and low-e film, insulated spacer, and TB frames (a.k.a. Heat Mirror® 66)

Exhibit 5.0A Details for each Energy-Conserving Measure (ECM), continued.

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM41		Employ air-tight construction (Advanced Drywall Approach). Heat recovery ventilator. Add 0.8 kWh/day to Base Loads as estimate of half-year operation of HRV.
ECM51		Replace existing heating system with a natural gas furnace of efficiency 78 percent. Decrease capacity from 75MBTU to 60MBTU.
ECM52		Replace existing heating system with a natural gas condenser furnace of steady-state efficiency 94 percent. Decrease capacity from 75MBTU to 40MBTU.
ECM53		SWITCH FUEL SOURCE TO ELECTRICITY - Replace existing heating system with electric radiant baseboard heaters of effective efficiency 100 percent. Do not change Base Loads 2.4 kWh/day figure. Subtract original cost of a 78%-eff. gas furnace. Benefit of re-acquired floor area
		INTEGRATED UPGRADES -
ECM95		Combine ECMs 11, 21, 22, 31, 41, 52. Fuel source: NATURAL GAS.
ECM96		Combine ECMs 11, 21, 22, 31, 41, 53 (as per R2000 house). Fuel source: ELECTRICITY.

5.1 HOUSE-BY-HOUSE ANALYSIS USING AVOIDED COSTS FOR ENERGY PRICES

5.1.1 HOUSE 'H1'

House H1 is classified as a "single family residence, detached, and built on a slab-on-grade foundation". It is a two-level house, and measures approximately 2,000 square feet in total floor area. It is heated with a forced air furnace that uses natural gas. Furnace "name-plate" specifications indicate an efficiency of 75 percent. Other parameters include the following:

- Windows and patio doors consisted of double-glazed glass, however thermally-bridged frames were not evident.
- Walls were framed with two-by-four studs from which it was inferred that existing insulation levels were nominally R12 (design specifications also indicated R12).
- Depth of ceiling insulation indicated R28 (nominal).

FUEL-SWITCHING IN 'H1'

In conservation measures ECM53 and ECM96, electricity replaces natural gas as an alternative energy source for space heating. Electric baseboard heating is used in each energy conservation measure. ECM96 also includes ceiling, wall, foundation, and ventilation upgrades. Exhibits 5.1A to C list findings for fuel switching analysis.

Exhibit 5.1A Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,457)	($1,642)	($1,212)
	PV Costs	($3,128)	($2,954)	($2,801)
	Net Benefits	$671	$1,312	$1,589
ECM96	PV Savings	$6,608	$4,415	$3,260
	PV Costs	$5,308	$5,387	$5,457
	Net Benefits	$1,300	($972)	($2,197)

Unadjusted supply costs. Avoided costs for energy prices.

Exhibit 5.1B Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,457)	($1,642)	($1,212)
	PV Costs	($3,378)	($3,203)	($3,051)
	Net Benefits	$921	$1,561	$1,839
ECM96	PV Savings	$6,608	$4,415	$3,260
	PV Costs	$3,712	$3,791	$3,861
	Net Benefits	$2,896	$624	($601)
Low supply costs (-30%). Avoided costs for energy prices.				

Using unadjusted supplier costs, exhibit 5.1A shows that ECM53 yielded positive net benefits for all three discount rates. However, both net savings and net costs were negative. In the case of net savings, electricity was more expensive to operate than natural gas. Switching to electricity would entail higher energy bills. Net savings would be negative. In terms of net costs, electric baseboards were less expensive to buy and install, as well as to maintain than natural gas heating[1]. Net costs would also turn out negative.

Different discount rates affect net savings and net costs in the following way: lowerinf rates increases the present value of future savings and costs; higher rates does the reverse. Exhibit 5.1A shows net savings decreasing with lower discount rates. Switching to electricity was more expensive when lower discount rates were used. In a similar way, net costs decreased with lower discount rates because electric baseboards require very little maintenance.

In ECM96, net savings and net costs were positive. Although electricity was more expensive than natural gas, the amount of energy saved after upgrading was sufficient to lower heating costs which, in turn, produced positive net savings. This was offset by additional costs needed to upgrade the house.

Not surprisingly, lower discount rates produced higher net savings. However, net costs decreased with lower discount rates. The reason for this comes from avoided incremental maintenance costs in choosing electric baseboards instead of a natural gas furnace system. Avoided gas maintenance costs loom larger, the lower the discount rate.

What happens should supplier costs decrease or increase by 30 percent? In exhibit 5.1B, the low supplier costs scenario produced little change in either ECM53 or ECM96. The relationship of net savings and net costs to discount rates remained the same as in exhibit 5.1A. Net benefits were again positive for ECM53, and mixed for ECM96.

Exhibit 5.1C shows that, although high supplier costs did not change the relationship of net savings and costs to discount rates[2], net benefits became uniformly negative for ECM96.

Exhibit 5.1C Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,457)	($1,642)	($1,212)
	PV Costs	($2,879)	($2,705)	($2,552)
	Net Benefits	$422	$1,063	$1,340
ECM96	PV Savings	$6,608	$4,415	$3,260
	PV Costs	$6,904	$6,983	$7,053
	Net Benefits	($296)	($2,568)	($3,793)
High supply costs (+30%). Avoided costs for energy prices.				

To summarize fuel switching, ECM53 yielded net benefits under all three discount rates and in all three supplier cost sensitivities. However, ECM96 did not consistently produce positive net benefits.

HEATING SYSTEM UPGRADES IN 'H1'

Attention now shifts to heating system upgrades. ECM41 introduces a heat recovery ventilator (HRV), and upgrades to reduce air leakage. Other building components were left unchanged. Net savings were found to be positive which indicated that savings from lower gas bills (over 2,500 kilowatt-hours saved as shown in appendix C) were greater than electricity costs required to operate the HRV. As expected, exhibits 5.1D to F show net savings and net costs increasing with lower discount rates. However, resulting net benefits were negative.

ECM52 upgrades the existing spark ignition gas furnace (78% efficiency) to a condenser furnace (94% efficiency). As expected, net savings are positive and increase with lower discount rates. Net costs also increase because of incremental maintenance costs (refer to appendix B for detailed costs).

Exhibit 5.1D Net benefits of Heating System Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	$971	$649	$479
	PV Costs	$5,604	$5,520	$5,445
	Net Benefits	($4,633)	($4,871)	($4,966)
ECM52	PV Savings	$4,621	$3,088	$2,280
	PV Costs	$1,483	$1,387	$1,305
	Net Benefits	$3,138	$1,701	$975
Unadjusted supply costs. Avoided costs for energy prices.				

Exhibit 5.1E Net benefits of Heating System Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	$971	$649	$479
	PV Costs	$4,247	$4,163	$4,089
	Net Benefits	($3,276)	($3,514)	($3,610)
ECM52	PV Savings	$4,621	$3,088	$2,280
	PV Costs	$1,354	$1,258	$1,176
	Net Benefits	$3,267	$1,830	$1,104
Low supply costs (-30%). Avoided costs for energy prices.				

Exhibit 5.1F Net benefits of Heating System Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	$971	$649	$479
	PV Costs	$6,960	$6,876	$6,802
	Net Benefits	($5,989)	($6,227)	($6,323)
ECM52	PV Savings	$4,621	$3,088	$2,280
	PV Costs	$1,612	$1,516	$1,434
	Net Benefits	$3,009	$1,572	$846
High supply costs (+30%). Avoided costs for energy prices.				

HOUSE ENVELOPE AND WINDOW UPGRADES IN 'H1'

Upgrades to the house envelope are discussed below in three categories: "opaque" envelope upgrades include ECM11, 12, 21, and 22; "glazing" or window upgrades include ECM31 to 36; and, an integrated upgrade has been included, ECM95[3]. Refer to exhibits 5.1G to J.

ECM11 and 12 represent upgrades to exterior wall insulation. ECM11 upgrades to an R20 wall (using "two-by-six" studs) from the conventional R12 wall ("two-by-four" studs). ECM12 upgrades to R40 (using "double two-by-six" studs). As expected, lower discount rates increase net savings. Net costs remain unchanged, however, because insulation upgrades only incurred initial costs. Results in all three supplier cost sensitivities were mixed for ECM11, but consistently negative for ECM12.

Increasing attic insulation, ECM21, returned mixed net benefits when unadjusted, and high, supplier costs were used. Positive net benefits were found when low supplier costs were used.

The foundation of a house is also part of its envelope (the surrounding ground is external to the house). ECM22 introduced insulation measures for foundation walls, slab edges, and the slab floor. Results were consistently positive across discount rates, and supplier costs.

Window ugrades are represented in ECM31 to 36. Window replacement was considered to be an ongoing cost. To account for this, 5 percent of the total window supply cost was added every five years.

ECM95 integrated measures ECM11, 21, 22, 41, and 52 to simulate R2000 standards. Natural gas remained the fuel source, but furnace efficiency was increased to 94 percent. Results were mixed. ECM95 only yielded positive net benefits in the low supplier cost sensitivity. This contradicts conservation literature which claims R2000 standards to yield generally positive net benefits (Hydro 1993, p. 131b; Byers 1989). One reason for ECM95's large negative figures comes from ECM41, the ventilation and air leakage upgrade. Earlier, it was shown that ECM41 produced large negative net benefits across all the cases analyzed. Some ECM95 results would change if costs for ECM41 can be reduced.

In summary, envelope upgrades produced disappointing results. Only the simplest upgrades – such as insulating attics (ECM21) and foundations (ECM22), and, to a lesser extent, window technologies ECM31 and 32 – yielded generally positive net benefits in the low supplier cost sensitivity.

Exhibit 5.1G Net benefits of Envelope and Window Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,459	$1,643	$1,213
	PV Costs	$1,954	$1,954	$1,954
	Net Benefits	$505	($311)	($741)
ECM12	PV Savings	$4,272	$2,854	$2,107
	PV Costs	$11,843	$11,843	$11,843
	Net Benefits	($7,571)	($8,989)	($9,736)
ECM21	PV Savings	$525	$351	$259
	PV Costs	$356	$356	$356
	Net Benefits	$169	($5)	($97)
ECM22	PV Savings	$1,768	$1,181	$872
	PV Costs	$552	$552	$552
	Net Benefits	$1,216	$629	$320
ECM31	PV Savings	$980	$655	$483
	PV Costs	$907	$856	$814
	Net Benefits	$73	($201)	($331)
ECM32	PV Savings	$1,286	$860	$635
	PV Costs	$1,106	$1,043	$991
	Net Benefits	$180	($183)	($356)
ECM33	PV Savings	$1,130	$755	$557
	PV Costs	$1,255	$1,183	$1,125
	Net Benefits	($125)	($428)	($568)
ECM34	PV Savings	$370	$247	$182
	PV Costs	$1,540	$1,452	$1,381
	Net Benefits	($1,170)	($1,205)	($1,199)
ECM35	PV Savings	$1,793	$1,198	$884
	PV Costs	$2,575	$2,428	$2,309
	Net Benefits	($782)	($1,230)	($1,425)
ECM36	PV Savings	$1,612	$1,077	$795
	PV Costs	$2,977	$2,807	$2,669
	Net Benefits	($1,365)	($1,730)	($1,874)
ECM95	PV Savings	$9,878	$6,600	$4,873
	PV Costs	$9,978	$9,810	$9,662
	Net Benefits	($100)	($3,210)	($4,789)

Unadjusted supply costs. Avoided costs for energy prices.

Exhibit 5.1H Net benefits of Envelope and Window Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,459	$1,643	$1,213
	PV Costs	$1,738	$1,738	$1,738
	Net Benefits	$721	($95)	($525)
ECM12	PV Savings	$4,272	$2,854	$2,107
	PV Costs	$11,065	$11,065	$11,065
	Net Benefits	($6,793)	($8,211)	($8,958)
ECM21	PV Savings	$525	$351	$259
	PV Costs	$249	$249	$249
	Net Benefits	$276	$102	$10
ECM22	PV Savings	$1,768	$1,181	$872
	PV Costs	$387	$387	$387
	Net Benefits	$1,381	$794	$485
ECM31	PV Savings	$980	$655	$483
	PV Costs	$635	$599	$569
	Net Benefits	$345	$56	($86)
ECM32	PV Savings	$1,286	$860	$635
	PV Costs	$774	$730	$694
	Net Benefits	$512	$130	($59)
ECM33	PV Savings	$1,130	$755	$557
	PV Costs	$878	$828	$787
	Net Benefits	$252	($73)	($230)
ECM34	PV Savings	$370	$247	$182
	PV Costs	$1,078	$1,016	$967
	Net Benefits	($708)	($769)	($785)
ECM35	PV Savings	$1,793	$1,198	$884
	PV Costs	$1,802	$1,700	$1,616
	Net Benefits	($9)	($502)	($732)
ECM36	PV Savings	$1,612	$1,077	$795
	PV Costs	$2,084	$1,965	$1,869
	Net Benefits	($472)	($888)	($1,074)
ECM95	PV Savings	$9,878	$6,600	$4,873
	PV Costs	$8,004	$7,836	$7,687
	Net Benefits	$1,874	($1,236)	($2,814)

Low supply costs (-30%). Avoided costs for energy prices.

Exhibit 5.1J Net benefits of Envelope and Window Upgrades for 'H1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,459	$1,643	$1,213
	PV Costs	$2,171	$2,171	$2,171
	Net Benefits	$288	($528)	($958)
ECM12	PV Savings	$4,272	$2,854	$2,107
	PV Costs	$12,621	$12,621	$12,621
	Net Benefits	($8,349)	($9,767)	($10,514)
ECM21	PV Savings	$525	$351	$259
	PV Costs	$463	$463	$463
	Net Benefits	$62	($112)	($204)
ECM22	PV Savings	$1,768	$1,181	$872
	PV Costs	$718	$718	$718
	Net Benefits	$1,050	$463	$154
ECM31	PV Savings	$980	$655	$483
	PV Costs	$1,180	$1,112	$1,058
	Net Benefits	($200)	($457)	($575)
ECM32	PV Savings	$1,286	$860	$635
	PV Costs	$1,438	$1,356	$1,289
	Net Benefits	($152)	($496)	($654)
ECM33	PV Savings	$1,130	$755	$557
	PV Costs	$1,631	$1,538	$1,462
	Net Benefits	($501)	($783)	($905)
ECM34	PV Savings	$370	$247	$182
	PV Costs	$2,002	$1,888	$1,795
	Net Benefits	($1,632)	($1,641)	($1,613)
ECM35	PV Savings	$1,793	$1,198	$884
	PV Costs	$3,347	$3,156	$3,001
	Net Benefits	($1,554)	($1,958)	($2,117)
ECM36	PV Savings	$1,612	$1,077	$795
	PV Costs	$3,870	$3,649	$3,470
	Net Benefits	($2,258)	($2,572)	($2,675)
ECM95	PV Savings	$9,878	$6,600	$4,873
	PV Costs	$11,953	$11,784	$11,636
	Net Benefits	($2,075)	($5,184)	($6,763)

High supply costs (+30%). Avoided costs for energy prices.

5.1.2 HOUSE 'H2'

House H2 can be classified as a "single family residence, detached, and built on a crawl space foundation". It is a two-level house, and measures approximately 2,100 square feet in total floor area. The main living area on the first floor is heated with a forced air furnace that uses natural gas. Furnace "name-plate" specifications indicate an efficiency of 75 percent. The upper floor, about one third of the total floor area, is heated with electric baseboard heaters. Other parameters include the following:

- Windows and patio doors consisted of double-glazed glass, however thermally-bridged frames were not evident.
- Walls were framed with two-by-four studs from which implied existing an R12 insulation level (design specifications also indicated R12).
- Depth of ceiling insulation indicated R28 (nominal).

FUEL-SWITCHING

Fuel switching required that electric baseboards replace the existing gas heating system. Although electric baseboards had already been installed to heat the second floor, billing records showed that gas was in fact the primary source of space heating. Annual gas consumption was close to 3,200 kilowatt-hours. Electric baseboards annually consumed about 900 kilowatt-hours (refer to appendix C).

Exhibits 5.1K to M list the findings. For similar reasons to H1, H2 net savings and net costs for ECM53 were negative (refer to section 5.1.1 for discussion). As expected, lower discount rates decreased net savings and net costs – negative numbers became more negative. However, positive net benefits still resulted because negative costs from choosing baseboard heating over gas heating offset higher energy costs.

In comparison to ECM53, net savings and net costs were positive for ECM96. Whereas net savings increased with lower discount rates, net costs decreased because future maintenance costs (of gas heating) were avoided.

ECM96 did not produce positive net benefits. Even in the low supplier cost sensitivity, net benefits were convincingly negative. One reason is space heating load was insufficiently reduced, and could not offset increased energy costs. A more probable reason is the integration of ECM41 (heat recovery ventilation and reduced air leakage). Later, exhibits 5.1N to P show ECM41 yielding large negative net benefits.

Exhibit 5.1K Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,182)	($1,458)	($1,077)
	PV Costs	($3,001)	($2,826)	($2,674)
	Net Benefits	$819	$1,368	$1,597
ECM96	PV Savings	$2,747	$1,836	$1,355
	PV Costs	$5,785	$5,864	$5,934
	Net Benefits	($3,038)	($4,028)	($4,579)
Unadjusted supply costs. Avoided costs for energy prices.				

Exhibit 5.1L Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,182)	($1,458)	($1,077)
	PV Costs	($3,212)	($3,037)	($2,885)
	Net Benefits	$1,030	$1,579	$1,808
ECM96	PV Savings	$2,747	$1,836	$1,355
	PV Costs	$4,114	$4,193	$4,263
	Net Benefits	($1,367)	($2,357)	($2,908)
Low supply costs (-30%). Avoided costs for energy prices.				

Exhibit 5.1M Net benefits of Fuel Switching from natural gas heating to electric baseboard heating for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM53	PV Savings	($2,182)	($1,458)	($1,077)
	PV Costs	($2,790)	($2,615)	($2,463)
	Net Benefits	$608	$1,157	$1,386
ECM96	PV Savings	$2,747	$1,836	$1,355
	PV Costs	$7,456	$7,535	$7,605
	Net Benefits	($4,709)	($5,699)	($6,250)

High supply costs (+30%). Avoided costs for energy prices.

HEATING SYSTEM UPGRADES

Exhibits 5.1N to P present findings for heating system upgrades. Net savings for ECM41 were negative indicating that electricity costs to operate the HRV exceeded gas savings (refer to appendix C for details on energy consumption)[4]. At lower discount rates, net savings became more negative as more and higher electricity bills were included. Coupled with positive net costs, the resulting net benefits for ECM41 were convincingly negative in all sensitivity analyses.

Less gas consumption resulted from upgrading to a condenser gas furnace (ECM52). The resulting positive net savings behaved as expected, increasing with lower discount rates. Likewise, more expensive maintenance costs for the condenser furnace increased net costs. ECM52 produced positive net benefits, but not in all discount rate sensitivities. One reason is the continued use of second floor baseboard heaters. This reduces the overall gas heating load which reduces the gas savings potential of a more energy efficient furnace.

Exhibit 5.1N Net benefits of Heating System Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	($478)	($319)	($236)
	PV Costs	$5,735	$5,651	$5,577
	Net Benefits	($6,213)	($5,970)	($5,813)
ECM52	PV Savings	$3,224	$2,154	$1,590
	PV Costs	$2,282	$2,198	$2,124
	Net Benefits	$942	($44)	($534)

Unadjusted supply costs. Avoided costs for energy prices.

Exhibit 5.1O Net benefits of Heating System Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	($478)	($319)	($236)
	PV Costs	$4,339	$4,255	$4,181
	Net Benefits	($4,817)	($4,574)	($4,417)
ECM52	PV Savings	$3,224	$2,154	$1,590
	PV Costs	$1,922	$1,838	$1,764
	Net Benefits	$1,302	$316	($174)

Low supply costs (-30%). Avoided costs for energy prices.

Exhibit 5.1P Net benefits of Heating System Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM41	PV Savings	($478)	($319)	($236)
	PV Costs	$7,131	$7,047	$6,973
	Net Benefits	($7,609)	($7,366)	($7,209)
ECM52	PV Savings	$3,224	$2,154	$1,590
	PV Costs	$2,642	$2,558	$2,484
	Net Benefits	$582	($404)	($894)

High supply costs (+30%). Avoided costs for energy prices.

House Envelope And Window Upgrades

Exhibits 5.1Q to S present findings for envelope and window upgrades. Upgrades to exterior wall insulation were represented in ECM11 and 12. Net savings increased with lower discount rates. However, because insulation upgrades did not require future maintenance or replacement costs, net costs remained constant for all three discount rates. In the same way, ECM21, 22 and 23 involved increasing net savings and constant net costs with lower discount rates.

Window upgrades exhibited both increasing net savings and net costs with lower discount rates. Window replacement was considered to be an ongoing cost. To account for this, 5 percent of the total window supply cost was added every five years.

ECM95 integrated five different upgrades. These are ECM11, 21, 22, 41, and 52. Natural gas remained the primary fuel source for space heating, but furnace efficiency was increased to 94 percent. Net savings and costs were positive, and increased with lower discount rates. The reason for increasing net costs is the presence of future maintenance costs for ECM41 and 52.

Results were consistently negative. One cause of these negative results comes from ECM41, the ventilation and air leakage upgrade (another might be the $1,459 lost floor area cost). Earlier, it was shown that ECM41 produced large negative net benefits across all the cases analyzed. Some results for ECM95 would change if costs for ECM41 can be reduced.

In summary, envelope upgrades were mixed. Window upgrades generally turned to be negative. While net savings increased with lower discount rates, net costs increased or remained constant depending on whether future maintenance costs.

Exhibit 5.1Q Net benefits of Envelope and Window Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,469	$1,650	$1,218
	PV Costs	$2,157	$2,157	$2,157
	Net Benefits	$312	($507)	($939)
ECM12	PV Savings	$3,887	$2,597	$1,918
	PV Costs	$13,611	$13,611	$13,611
	Net Benefits	($9,724)	($11,014)	($11,693)
ECM21	PV Savings	$601	$402	$296
	PV Costs	$367	$367	$367
	Net Benefits	$234	$35	($71)
ECM22	PV Savings	$362	$242	$179
	PV Costs	$556	$556	$556
	Net Benefits	($194)	($314)	($377)
ECM23	PV Savings	$458	$306	$226
	PV Costs	$320	$320	$320
	Net Benefits	$138	($14)	($94)
ECM31	PV Savings	$1,233	$824	$608
	PV Costs	$1,590	$1,499	$1,425
	Net Benefits	($357)	($675)	($817)
ECM32	PV Savings	$2,005	$1,340	$989
	PV Costs	$2,476	$2,334	$2,220
	Net Benefits	($471)	($994)	($1,231)
ECM33	PV Savings	$1,399	$935	$690
	PV Costs	$2,049	$1,932	$1,837
	Net Benefits	($650)	($997)	($1,147)
ECM34	PV Savings	$2,349	$1,570	$1,159
	PV Costs	$2,719	$2,563	$2,437
	Net Benefits	($370)	($993)	($1,278)
ECM35	PV Savings	$2,615	$1,747	$1,290
	PV Costs	$4,682	$4,415	$4,198
	Net Benefits	($2,067)	($2,668)	($2,908)
ECM36	PV Savings	$2,369	$1,583	$1,169
	PV Costs	$5,933	$5,595	$5,320
	Net Benefits	($3,564)	($4,012)	($4,151)
ECM95	PV Savings	$6,075	$4,059	$2,997
	PV Costs	$11,097	$10,929	$10,781
	Net Benefits	($5,022)	($6,870)	($7,784)

Unadjusted supply costs. Avoided costs for energy prices.

Exhibit 5.1R Net benefits of Envelope and Window Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,469	$1,650	$1,218
	PV Costs	$1,948	$1,948	$1,948
	Net Benefits	$521	($298)	($730)
ECM12	PV Savings	$3,887	$2,597	$1,918
	PV Costs	$12,809	$12,809	$12,809
	Net Benefits	($8,922)	($10,212)	($10,891)
ECM21	PV Savings	$601	$402	$296
	PV Costs	$257	$257	$257
	Net Benefits	$344	$145	$39
ECM22	PV Savings	$362	$242	$179
	PV Costs	$389	$389	$389
	Net Benefits	($27)	($147)	($210)
ECM23	PV Savings	$458	$306	$226
	PV Costs	$224	$224	$224
	Net Benefits	$234	$82	$2
ECM31	PV Savings	$1,233	$824	$608
	PV Costs	$1,113	$1,049	$998
	Net Benefits	$120	($225)	($390)
ECM32	PV Savings	$2,005	$1,340	$989
	PV Costs	$1,733	$1,634	$1,554
	Net Benefits	$272	($294)	($565)
ECM33	PV Savings	$1,399	$935	$690
	PV Costs	$1,434	$1,352	$1,286
	Net Benefits	($35)	($417)	($596)
ECM34	PV Savings	$2,349	$1,570	$1,159
	PV Costs	$1,903	$1,794	$1,706
	Net Benefits	$446	($224)	($547)
ECM35	PV Savings	$2,615	$1,747	$1,290
	PV Costs	$3,277	$3,090	$2,939
	Net Benefits	($662)	($1,343)	($1,649)
ECM36	PV Savings	$2,369	$1,583	$1,169
	PV Costs	$4,153	$3,916	$3,724
	Net Benefits	($1,784)	($2,333)	($2,555)
ECM95	PV Savings	$6,075	$4,059	$2,997
	PV Costs	$8,855	$8,687	$8,539
	Net Benefits	($2,780)	($4,628)	($5,542)

Low supply costs (-30%). Avoided costs for energy prices.

Exhibit 5.1S Net benefits of Envelope and Window Upgrades for 'H2'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM11	PV Savings	$2,469	$1,650	$1,218
	PV Costs	$2,367	$2,367	$2,367
	Net Benefits	$102	($717)	($1,149)
ECM12	PV Savings	$3,887	$2,597	$1,918
	PV Costs	$14,413	$14,413	$14,413
	Net Benefits	($10,526)	($11,816)	($12,495)
ECM21	PV Savings	$601	$402	$296
	PV Costs	$477	$477	$477
	Net Benefits	$124	($75)	($181)
ECM22	PV Savings	$362	$242	$179
	PV Costs	$722	$722	$722
	Net Benefits	($360)	($480)	($543)
ECM23	PV Savings	$458	$306	$226
	PV Costs	$416	$416	$416
	Net Benefits	$42	($110)	($190)
ECM31	PV Savings	$1,233	$824	$608
	PV Costs	$2,067	$1,949	$1,853
	Net Benefits	($834)	($1,125)	($1,245)
ECM32	PV Savings	$2,005	$1,340	$989
	PV Costs	$3,218	$3,035	$2,886
	Net Benefits	($1,213)	($1,695)	($1,897)
ECM33	PV Savings	$1,399	$935	$690
	PV Costs	$2,663	$2,511	$2,388
	Net Benefits	($1,264)	($1,576)	($1,698)
ECM34	PV Savings	$2,349	$1,570	$1,159
	PV Costs	$3,534	$3,332	$3,169
	Net Benefits	($1,185)	($1,762)	($2,010)
ECM35	PV Savings	$2,615	$1,747	$1,290
	PV Costs	$6,087	$5,739	$5,457
	Net Benefits	($3,472)	($3,992)	($4,167)
ECM36	PV Savings	$2,369	$1,583	$1,169
	PV Costs	$7,713	$7,273	$6,916
	Net Benefits	($5,344)	($5,690)	($5,747)
ECM95	PV Savings	$6,075	$4,059	$2,997
	PV Costs	$13,339	$13,171	$13,023
	Net Benefits	($7,264)	($9,112)	($10,026)

High supply costs (+30%). Avoided costs for energy prices.

5.1.3 HOUSE 'TH1'

TH1 is one of three attached townhouse units built on a concrete slab foundation. Each unit consists of three floors. Total floor area for TH1 is approximately 1,800 square feet. Electric baseboard heaters provide primary space heating while a natural gas fireplace located on the ground floor can be used to provide secondary heating. The building was built to R2000 standards. Component parameters include the following:

- Windows consisted of triple-glazed glass except "slider" windows which were double-glazed. Patio doors were also double-glazed. Window frames and patio door frames were thermally-bridged.
- Design specifications required two-by-six stud framed walls and R20 insulation.
- Depth of ceiling insulation indicated R40.

WINDOW UPGRADES ONLY

TH1 was already built to standards that this study had set out to analyze. Except for window technology, upgrading of other building components lies beyond the scope of this study. Consequently, upgrades analysis for TH1 was limited to windows and other "glazing" (such as skylights, and patio doors).

Results for the five alternative window technologies (not including ECM34) are listed in exhibits 5.1T to V. In terms of supply cost, ECM34 (triple glazed windows) is more expensive than either ECM31 or 33. This can be seen in negative net costs for these two alternatives. Net savings are also negative for windows of lower insulation value than ECM34. ECM31, 32 and 33 are considered of lower insulation value than ECM34[5].

Lower discount rates affect both net savings and net costs. For net savings, the reason is obvious – a lower discount rate incorporates more energy savings. For net costs, the reason is the presence of future replacement costs. In estimating net benefits of window upgrades, it was assumed that five percent of windows would require replacement every five years.

Exhibit 5.1T Net benefits of Window Upgrades for 'TH1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM31	PV Savings	($598)	($400)	($295)
	PV Costs	($739)	($697)	($663)
	Net Benefits	$141	$297	$368
ECM32	PV Savings	($27)	($18)	($13)
	PV Costs	$108	$102	$97
	Net Benefits	($135)	($120)	($110)
ECM33	PV Savings	($400)	($267)	($197)
	PV Costs	($349)	($329)	($313)
	Net Benefits	($51)	$62	$116
ECM35	PV Savings	$727	$486	$359
	PV Costs	$1,588	$1,497	$1,424
	Net Benefits	($861)	($1,011)	($1,065)
ECM36	PV Savings	$1,093	$730	$539
	PV Costs	$2,899	$2,734	$2,599
	Net Benefits	($1,806)	($2,004)	($2,060)

Unadjusted supply costs. Avoided costs for energy prices.

Exhibit 5.1U Net benefits of Window Upgrades for 'TH1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM31	PV Savings	($598)	($400)	($295)
	PV Costs	($961)	($906)	($861)
	Net Benefits	$363	$506	$566
ECM32	PV Savings	($27)	($18)	($13)
	PV Costs	$76	$71	$68
	Net Benefits	($103)	($89)	($81)
ECM33	PV Savings	($400)	($267)	($197)
	PV Costs	($454)	($428)	($407)
	Net Benefits	$54	$161	$210
ECM35	PV Savings	$727	$486	$359
	PV Costs	$1,112	$1,048	$997
	Net Benefits	($385)	($562)	($638)
ECM36	PV Savings	$1,093	$730	$539
	PV Costs	$2,029	$1,914	$1,820
	Net Benefits	($936)	($1,184)	($1,281)

Low supply costs (-30%). Avoided costs for energy prices.

Exhibit 5.1V Net benefits of Window Upgrades for 'TH1'.

		Real Discount Rate 5%	Real Discount Rate 8%	Real Discount Rate 11%
ECM31	PV Savings	($598)	($400)	($295)
	PV Costs	($517)	($488)	($464)
	Net Benefits	($81)	$88	$169
ECM32	PV Savings	($27)	($18)	($13)
	PV Costs	$141	$133	$126
	Net Benefits	($168)	($151)	($139)
ECM33	PV Savings	($400)	($267)	($197)
	PV Costs	($244)	($230)	($219)
	Net Benefits	($156)	($37)	$22
ECM35	PV Savings	$727	$486	$359
	PV Costs	$2,064	$1,946	$1,851
	Net Benefits	($1,337)	($1,460)	($1,492)
ECM36	PV Savings	$1,093	$730	$539
	PV Costs	$3,769	$3,554	$3,379
	Net Benefits	($2,676)	($2,824)	($2,840)

High supply costs (+30%). Avoided costs for energy prices.

5.2 COMPARING NET BENEFITS FOR ALL HOUSES

5.2A SUMMARY OF AVOIDED ENERGY COST ANALYSES

Findings of analyses using avoided energy costs are presented in exhibits 5.2A, B and C (see pages following). At 5 percent discount rate, exhibit 5.2A shows that, in H1, net benefits were positive in all three supplier cost sensitivities for ECM53 (fuel switching), ECM52 (heating system upgrade), ECM11, ECM21 and ECM22 (envelope upgrade). The fuel switch upgrade, ECM96, might be considered net beneficial if the negative result in the high supplier cost sensitivity can be considered marginal compared with the results in unadjusted and low supplier cost sensitivities. Likewise, an argument can be made in favour of window upgrades ECM31 and ECM32.

However, the remaining upgrades did not fare so well. Window upgrades ECM34, 35 and 36 yielded negative results across all three supplier cost sensitivities. Upgrading to a condenser gas furnace (ECM52) yielded similar negative results, as did R40 wall insulation upgrade (ECM12). In upgrades ECM33 (window) and ECM95 (integrated), each managed to produce positive net benefits in the low supplier cost sensitivity.

In H2, results were similar to H1. Two notable exceptions occurred in ECM96 and ECM22. Switching fuels from gas to electricity and undertaking an R2000 upgrade (ECM96) produced negative net benefits across all three supplier cost sensitivities in H2. These net benefits are significantly more negative in H2 than in H1. One reason for this comes from total energy saved. In appendix C, HOT2000 results for ECM96 indicate that close to 18,000 kilowatt-hours (64 gigajoules) were saved in H1, while just over 11,000 kilowatt-hours (40 gigajoules) were saved in H2.

Unlike in H1, upgrading insulation around the concrete foundation (ECM22) in H2 yielded negative results. However, insulating the crawl space walls, floor and ceiling (ECM23) did produce consistently positive net benefits.

In TH1, five window upgrades[6] were analyzed. ECM35 and 36 did not produce positive net benefits. ECM31 produced positive results for low and unadjusted supplier cost sensitivities. ECM33 produced positive results for the low supplier cost sensitivity. The result was that two window "downgrades", ECM31 and 33, produced positive results.

NET BENEFITS IN THE FACE OF HIGHER DISCOUNT RATES

The effect of higher discount rates is to discount costs and savings occurring in the future. Exhibits 5.2B and C illustrate resulting changes to net benefits. In H1 and H2, net benefits were generally lower with discount rates of 8 and 11 percent. Fuel switching, ECM53, was the only exception. The reason for this lies in the higher cost for electricity. A higher discount rate discounts future costs for electricity consumption. As a result, net benefits increased with higher discount rates.

At 8 percent discount rate, upgrades that produced positive net benefits in all three supplier cost sensitivities were,

- for H1, ECM53, 52 and 22;
- for H2, ECM53; and,
- for TH1, ECM31.

In TH1, window upgrades ECM35 and 36 produced lower net benefits with higher discount rates while ECM31, 32 and 33 (in essence, window "downgrades") did the reverse. Upon closer examination of ECM35 and 36, net savings and net costs were positive. Higher discount rates served to discount future incremental savings and costs, but net costs decreased more slowly than net savings as the discount rate rose. Net benefits therefore decreased.

At 11 percent discount rate, upgrades that produced positive results across all three supplier cost sensitivities were,

- for H1, ECM53, 52 and 22;
- for H2, ECM 53; and,
- for TH1, ECM31 and 33.

In ECM31 and 33, both net savings and net costs were negative. In this case, higher discount rates discounted more costly heating bills and less costly window repairs occurring in the future. Both net savings and costs increased with higher discount rates, but net savings increased more quickly than net costs. Net benefits therefore increased.

ECM32 entailed negative net savings and positive net costs. Higher discount rates discounted future higher heating bills. This increased net savings. At the same time, higher discount rates discounted future window repair costs which reduced net costs. Although net benefits increased with higher discount rates, they remained negative in all three supplier cost sensitivities.

5.2B Summary of Net Benefits Using Social Costs and Avoided Costs for Energy Prices

Higher costs for energy served to increase benefits from conservation. Upgrade measures that produced positive net savings in the avoided energy cost analysis were found to produce even larger net savings in the social and avoided cost analysis. Net benefits therefore also increased.

Measures that previously produced negative net savings incurred more negative figures in the current analysis. The reason is negative savings mean a move to greater energy consumption and higher bills. The addition of social costs increases the cost of greater energy consumption, and thus yields even higher bills. Net benefits in this case decreased.

Exhibits 5.2D to E present findings for the social and avoided cost analysis. Upgrades whose net benefits changed substantially from the avoided cost analysis were the following:

1. In H1 with 5 percent discount rate,
   - ECM31, 32, 95 and 96 changed from mixed negative and positive net benefits to positive net benefits across all supplier cost sensitivities,
   - ECM35 changed from all negative net benefits to mixed net benefits.
2. In H2 with 5 percent discount rate,
   - ECM22, 33 and 96 changed from all negative net benefits to mixed net benefits.
3. In TH1 with 5 percent discount rate,
   - ECM33 changed from mixed net benefits to all negative net benefits.
4. In H1 with 8 percent discount rate,
   - ECM11, 33 and 95 changed from all negative net benefits to mixed net benefits.
5. In H2 with 8 percent discount rate,
   - ECM52 changed from mixed net benefits to all positive net benefits,
   - ECM11 and 34 changed from all negative net benefits to mixed net benefits.
6. In TH1 with 8 percent discount rate, there were no changes.
7. In H1 with 11 percent discount rate,
   - ECM31, 32 and 96 changed from all negative net benefits to mixed net benefits.
8. In H2 with 11 percent discount rate,
   - ECM52 changed from all negative net benefits to mixed net benefits.
9. In TH1 with 11 percent discount rate,
   - ECM33 changed from all positive net benefits to mixed net benefits.

Exhibit 5.2A

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES

Assumptions: Avoided Costs for Energy; Discount Rate is 5%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$921	$671	$422	$1,030	$819	$608	n.a.	n.a.	n.a.
ECM96	$2,896	$1,300	($296)	($1,367)	($3,038)	($4,709)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($3,276)	($4,633)	($5,989)	($4,817)	($6,213)	($7,609)	n.a.	n.a.	n.a.
ECM52	$3,267	$3,138	$3,009	$1,302	$942	$582	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	$721	$505	$288	$521	$312	$102	n.a.	n.a.	n.a.
ECM12	($6,793)	($7,571)	($8,349)	($8,922)	($9,724)	($10,526)	n.a.	n.a.	n.a.
ECM21	$276	$169	$62	$344	$234	$124	n.a.	n.a.	n.a.
ECM22	$1,381	$1,216	$1,050	($27)	($194)	($360)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$234	$138	$42	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	$345	$73	($200)	$120	($357)	($834)	$363	$141	($81)
ECM32	$512	$180	($152)	$272	($471)	($1,213)	($103)	($135)	($168)
ECM33	$252	($125)	($501)	($35)	($650)	($1,264)	$54	($51)	($156)
ECM34	($708)	($1,170)	($1,632)	$446	($370)	($1,185)	n.a.	n.a.	n.a.
ECM35	($9)	($782)	($1,554)	($662)	($2,067)	($3,472)	($385)	($861)	($1,337)
ECM36	($472)	($1,365)	($2,258)	($1,784)	($3,564)	($5,344)	($936)	($1,806)	($2,676)
Integrated Upgrade									
ECM95	$1,874	($100)	($2,075)	($2,780)	($5,022)	($7,264)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for installed levels in H1 and H2.

Exhibit 5.2B

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES
Assumptions: Avoided Costs for Energy; Discount Rate is 8%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$1,561	$1,312	$1,063	$1,579	$1,368	$1,157	n.a.	n.a.	n.a.
ECM96	$624	($972)	($2,568)	($2,357)	($4,028)	($5,699)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($3,514)	($4,871)	($6,227)	($4,574)	($5,970)	($7,366)	n.a.	n.a.	n.a.
ECM52	$1,830	$1,701	$1,572	$316	($44)	($404)	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	($95)	($311)	($528)	($298)	($507)	($717)	n.a.	n.a.	n.a.
ECM12	($8,211)	($8,989)	($9,767)	($10,212)	($11,014)	($11,816)	n.a.	n.a.	n.a.
ECM21	$102	($5)	($112)	$145	$35	($75)	n.a.	n.a.	n.a.
ECM22	$794	$629	$463	($147)	($314)	($480)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$82	($14)	($110)	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	$56	($201)	($457)	($225)	($675)	($1,125)	$506	$297	$88
ECM32	$130	($183)	($496)	($294)	($994)	($1,695)	($89)	($120)	($151)
ECM33	($73)	($428)	($783)	($417)	($997)	($1,576)	$161	$62	($37)
ECM34	($769)	($1,205)	($1,641)	($224)	($993)	($1,762)	n.a.	n.a.	n.a.
ECM35	($502)	($1,230)	($1,958)	($1,343)	($2,668)	($3,992)	($562)	($1,011)	($1,460)
ECM36	($888)	($1,730)	($2,572)	($2,333)	($4,012)	($5,690)	($1,184)	($2,004)	($2,824)
Integrated Upgrade									
ECM95	($1,236)	($3,210)	($5,184)	($4,628)	($6,870)	($9,112)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for *installed levels in* H1 *and* H2.

Exhibit 5.2C

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES
Assumptions: Avoided Costs for Energy; Discount Rate is 11%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$1,839	$1,589	$1,340	$1,808	$1,597	$1,386	n.a.	n.a.	n.a.
ECM96	($601)	($2,197)	($3,793)	($2,908)	($4,579)	($6,250)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($3,610)	($4,966)	($6,323)	($4,417)	($5,813)	($7,209)	n.a.	n.a.	n.a.
ECM52	$1,104	$975	$846	($174)	($534)	($894)	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	($525)	($741)	($958)	($730)	($939)	($1,149)	n.a.	n.a.	n.a.
ECM12	($8,958)	($9,736)	($10,514)	($10,891)	($11,693)	($12,495)	n.a.	n.a.	n.a.
ECM21	$10	($97)	($204)	$39	($71)	($181)	n.a.	n.a.	n.a.
ECM22	$485	$320	$154	($210)	($377)	($543)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$2	($94)	($190)	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	($86)	($331)	($575)	($390)	($817)	($1,245)	$566	$368	$169
ECM32	($59)	($356)	($654)	($565)	($1,231)	($1,897)	($81)	($110)	($139)
ECM33	($230)	($568)	($905)	($596)	($1,147)	($1,698)	$210	$116	$22
ECM34	($785)	($1,199)	($1,613)	($547)	($1,278)	($2,010)	n.a.	n.a.	n.a.
ECM35	($732)	($1,425)	($2,117)	($1,649)	($2,908)	($4,167)	($638)	($1,065)	($1,492)
ECM36	($1,074)	($1,874)	($2,675)	($2,555)	($4,151)	($5,747)	($1,281)	($2,060)	($2,840)
Integrated Upgrade									
ECM95	($2,814)	($4,789)	($6,763)	($5,542)	($7,784)	($10,026)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for installed levels in H1 and H2.

Exhibit 5.2D

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES

Assumptions: Avoided Costs and Social Costs for Energy; Discount Rate is 5%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$2,241	$1,991	$1,742	$1,928	$1,717	$1,506	n.a.	n.a.	n.a.
ECM96	$5,592	$3,996	$2,400	$276	($1,395)	($3,066)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($2,958)	($4,315)	($5,671)	($4,890)	($6,286)	($7,682)	n.a.	n.a.	n.a.
ECM52	$4,478	$4,349	$4,220	$2,148	$1,788	$1,428	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	$1,367	$1,151	$934	$1,066	$857	$647	n.a.	n.a.	n.a.
ECM12	($5,672)	($6,450)	($7,228)	($8,004)	($8,806)	($9,608)	n.a.	n.a.	n.a.
ECM21	$414	$307	$200	$435	$325	$215	n.a.	n.a.	n.a.
ECM22	$1,845	$1,680	$1,514	$28	($139)	($305)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$303	$207	$111	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	$602	$330	$57	$341	($136)	($613)	$272	$50	($172)
ECM32	$850	$518	$186	$695	($48)	($790)	($107)	($139)	($172)
ECM33	$548	$171	($205)	$229	($386)	($1,000)	($7)	($112)	($217)
ECM34	($611)	($1,073)	($1,535)	$959	$143	($672)	n.a.	n.a.	n.a.
ECM35	$461	($312)	($1,084)	($79)	($1,484)	($2,889)	($274)	($750)	($1,226)
ECM36	($49)	($942)	($1,835)	($1,266)	($3,046)	($4,826)	($770)	($1,640)	($2,510)
Integrated Upgrade									
ECM95	$4,530	$2,556	$581	($1,227)	($3,469)	($5,711)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for installed levels in H1 and H2.

Exhibit 5.2E

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES
Assumptions: Avoided Costs and Social Costs for Energy; Discount Rate is 8%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$2,443	$2,194	$1,945	$2,179	$1,968	$1,757	n.a.	n.a.	n.a.
ECM96	$2,426	$830	($766)	($1,260)	($2,931)	($4,602)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($3,302)	($4,659)	($6,015)	($4,623)	($6,019)	($7,415)	n.a.	n.a.	n.a.
ECM52	$2,639	$2,510	$2,381	$881	$521	$161	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	$336	$120	($97)	$66	($143)	($353)	n.a.	n.a.	n.a.
ECM12	($7,461)	($8,239)	($9,017)	($9,599)	($10,401)	($11,203)	n.a.	n.a.	n.a.
ECM21	$194	$87	($20)	$206	$96	($14)	n.a.	n.a.	n.a.
ECM22	$1,104	$939	$773	($110)	($277)	($443)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$128	$32	($64)	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	$228	($29)	($285)	($78)	($528)	($978)	$445	$236	$27
ECM32	$355	$42	($271)	($11)	($711)	($1,412)	($92)	($123)	($154)
ECM33	$125	($230)	($585)	($241)	($821)	($1,400)	$120	$21	($78)
ECM34	($704)	($1,140)	($1,576)	$119	($650)	($1,419)	n.a.	n.a.	n.a.
ECM35	($188)	($916)	($1,644)	($953)	($2,278)	($3,602)	($488)	($937)	($1,386)
ECM36	($605)	($1,447)	($2,289)	($1,987)	($3,666)	($5,344)	($1,073)	($1,893)	($2,713)
Integrated Upgrade									
ECM95	$539	($1,435)	($3,409)	($3,590)	($5,832)	($8,074)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for installed levels in H1 and H2.

Exhibit 5.2F

SUMMARY OF NET BENEFITS ARISING FROM CONSERVATION UPGRADES
Assumptions: Avoided Costs and Social Costs for Energy; Discount Rate is 11%.

House:	H1			H2			TH1		
Supplier Cost Adjustment:	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)	Low (-30%)	Unadjusted	High (+30%)
Fuel Switching									
ECM53	$2,490	$2,240	$1,991	$2,252	$2,041	$1,830	n.a.	n.a.	n.a.
ECM96	$729	($867)	($2,463)	($2,097)	($3,768)	($5,439)	n.a.	n.a.	n.a.
Heating System Upgrades									
ECM41	($3,453)	($4,809)	($6,166)	($4,453)	($5,849)	($7,245)	n.a.	n.a.	n.a.
ECM52	$1,701	$1,572	$1,443	$244	($116)	($476)	n.a.	n.a.	n.a.
Opaque Envelope Upgrades									
ECM11	($206)	($422)	($639)	($461)	($670)	($880)	n.a.	n.a.	n.a.
ECM12	($8,404)	($9,182)	($9,960)	($10,439)	($11,241)	($12,043)	n.a.	n.a.	n.a.
ECM21	$78	($29)	($136)	$84	($26)	($136)	n.a.	n.a.	n.a.
ECM22	$714	$549	$383	($183)	($350)	($516)	n.a.	n.a.	n.a.
ECM23	n.a.	n.a.	n.a.	$36	($60)	($156)	n.a.	n.a.	n.a.
Window Upgrades									
ECM31	$41	($204)	($448)	($281)	($708)	($1,136)	$521	$323	$124
ECM32	$107	($190)	($488)	($356)	($1,022)	($1,688)	($83)	($112)	($141)
ECM33	($83)	($421)	($758)	($465)	($1,016)	($1,567)	$180	$86	($8)
ECM34	($737)	($1,151)	($1,565)	($294)	($1,025)	($1,757)	n.a.	n.a.	n.a.
ECM35	($500)	($1,193)	($1,885)	($1,362)	($2,621)	($3,880)	($584)	($1,011)	($1,438)
ECM36	($865)	($1,665)	($2,466)	($2,300)	($3,896)	($5,492)	($1,199)	($1,978)	($2,758)
Integrated Upgrade									
ECM95	($1,504)	($3,479)	($5,453)	($4,776)	($7,018)	($9,260)	n.a.	n.a.	n.a.

In TH1, only window upgrades were analyzed. TH1 was installed with ECM34 windows. Therefore, ECM31 to 33 represent 'downgrades' to existing windows.
Refer to appendix A for installed levels in H1 and H2.

5.3 WHAT IT ALL MEANS

Rationales that support higher housing standards are based on better-built houses yielding positive net benefits. Conservation advocates consider higher housing standards an efficient policy alternative to large-scale power generation facilities in British Columbia. In exhibits 5.2A to F, findings both supported and contradicted this view. At this point, it would be useful to interpret these findings to estimate where conservation standards might yield efficiency benefits.

UPGRADES TO THE OPAQUE HOUSE ENVELOPE[7]

1. INCREASE EXTERIOR WALL INSULATION FROM R12 TO R20 USING "TWO-BY-SIX" WALL CONSTRUCTION (UPGRADE "ECM11").
   - Using Avoided Costs For Energy – Net benefits were positive for houses H1 and H2[8] across the range of supplier costs in the 5% discount rate case. A positive net benefit means the upgrade is worth doing. However, negative net benefits resulted when 8% was used. In the "unadjusted supplier cost" scenario, net benefits switched from positive to negative at about 7%. This is referred to as the "break-even" point.
   - Using Social Cost Premiums For Energy – In general, the effect of incorporating social costs into energy costs is to increase net benefits. ECM11 is worth doing across the range of supplier costs in the 5% discount rate case. The break-even range turned out to be approximately 8%.
   - Costs from lost floor area were significant factors in arriving at negative net benefits. For H1, the cost of lost floor area was $1,233. For H2, the cost was $1,459. In the absence of lost floor area costs,

ECM11 would be worth doing across the range of energy costs, supplier costs and discount rates.

2. INCREASE EXTERIOR WALL INSULATION FROM R12 TO R40 USING "DOUBLE-TWO-BY-SIX" CONSTRUCTION (ECM12).
   - Net benefits were negative in every analysis of ECM12 implying that this upgrade is not worth doing.
   - Costs from lost floor area were significant factors in arriving at these negative net benefits. For H1, the cost of lost floor area was $9,250. For H2, the cost was $10,938. In the absence of lost floor area costs, the break-even point for ECM12 was between 10% and 11%.
3. INCREASE ATTIC INSULATION FROM R28 TO R40 (ECM21).
   - Avoided Costs For Energy – This upgrade is worth doing across the range of supplier costs at the 5% discount rate. Break-even occurred at 8% for H1, and 9% for H2.
   - Social Cost Premiums For Energy – Results were similar to the case using Avoided Costs. Break-even occurred for both houses at 10%.
   - ECM21 did not change total floor area.
4. INCREASE INSULATION IN HOUSE FOUNDATIONS TO R8 (ECM22, ECM23).
   - Upgrades ECM22 and ECM23 combine to insulate foundation walls and floors as was done for house H2. In addition, the two upgrades can be adopted individually to insulate either foundation walls or the slab floor as in the case of house H1.
   - Avoided Costs For Energy – In H1, ECM22 yielded positive net benefits across the range of supplier costs and discount rates. This upgrade is worth doing. In H2, the combination of ECM22 and 23 did not generally yield positive net benefits and is considered not worth doing.

- Social Cost Premiums For Energy – In H1, the social cost premium for natural gas further emphasizes net benefits of ECM22 as a worthwhile upgrade. In H2, social costs for electricity and natural gas increased net benefits so that a break-even point for ECM22 and 23 occurred at 5%.

UPGRADES TO WINDOWS

5. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "DOUBLE-GLAZED WITH THERMALLY-BRIDGED (DG/TB) ALUMINUM FRAME" (ECM31).
   - Avoided Costs For Energy – In H2, this upgrade is not worth doing. In H1, this upgrade is worth doing up to about 6%. In TH1, ECM31 turns out to be a "downgrade" in insulation level[9]. Nevertheless, ECM31 is worth doing in all three discount rate cases. The results for TH1 are significant because they suggest that "DG/TB" windows would have been a better investment than the existing triple-glazed and thermally-bridged windows.
   - Social Cost Premiums For Energy – In H2, ECM31 continues to produce negative net benefits. The break-even point in H1 has changed and ECM31 is worth doing up to about 8%. In TH1, the social premium for electricity reduced net benefits. However, ECM31 continues to be worth doing in all three discount rate cases.
6. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "DOUBLE-GLAZED WITH VINYL FRAME" (ECM32).
   - Avoided Costs For Energy – In H2, this upgrade is not worth doing. In H1, this upgrade is worth doing up to between 6% and 7%. In TH1, this "downgrade" is not worth doing.
   - Social Cost Premiums For Energy – In H2, ECM32 continued to produce negative net benefits. The break-even point in H1 has

changed and ECM32 is worth doing up to about 9%. In TH1, this "downgrade" is again not worth doing.

7. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "DOUBLE-GLAZED WITH THERMALLY-BRIDGED (DG/TB) ALUMINUM FRAME AND ARGON-FILLED AIR SPACE" (ECM33).
   - Avoided Costs For Energy – In H1 and H2, this upgrade is not worth doing. In TH1, ECM33 is worth doing at discount rates above 8%[10].
   - Social Cost Premiums For Energy – In H2, ECM33 continues to produce negative net benefits. The break-even point in H1 has changed and ECM33 is worth doing up to 6%. In TH1, ECM33 is again worth doing at discount rates above 8%.
8. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "TRIPLE-GLAZED WITH THERMALLY-BRIDGED (TG/TB) ALUMINUM FRAME" (ECM34).
   - Avoided Costs For Energy – In H1 and H2, this upgrade is not worth doing. TH1 was not analyzed in this case because the townhouse was originally installed with "TG/TB" windows.
   - Social Cost Premiums For Energy – In H1, ECM34 continues to produce negative net benefits. The break-even point in H2 has changed and ECM34 is worth doing at 5%.
9. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "DOUBLE-GLAZED WITH VINYL FRAME AND LOW 'E' FILM" (ECM35).
   - Upgrade ECM35 was found to be not worth doing in all three houses[11].
10. UPGRADE WINDOWS FROM "DOUBLE-GLAZED (DG) WITH SOLID ALUMINUM FRAME" TO "DOUBLE-GLAZED WITH THERMALLY-BRIDGED ALUMINUM FRAME, INSULATED SPACER AND LOW 'E' FILM" (ECM36).

- Upgrade ECM36 was found to be not worth doing in all three houses.

UPGRADES TO THE HEATING SYSTEM

11. UPGRADE EXISTING "SPARK IGNITION" NATURAL GAS FURNACE TO "CONDENSER" GAS FURNACE (ECM52).
    - Avoided Costs For Energy – In H1, the furnace upgrade is worth doing across the range of discount rates analyzed. However, this was not found to be the case in H2. Upgrading from the spark ignition furnace is not worth doing at discount rates higher than 5%.
    - Social Cost Premiums For Energy – ECM52 continues to be worth doing in H1. In H2, the break-even point has been increased to about 9%.
12. INSTALL A HEAT RECOVERY VENTILATOR AND REDUCE NATURAL AIR INFILTRATION TO APPROXIMATELY 4 AIR CHANGES PER HOUR USING 'ADVANCED DRYWALL APPROACH' (ECM41).
    - In all analyzed cases , upgrade ECM41 was found to be not worth doing in both H1 and H2.

COMBINING A NUMBER OF UPGRADES

13. UPGRADE A HOUSE BY USING R40 ATTICS, R20 EXTERIOR WALLS, R8 FOUNDATION COMPONENTS, DOUBLE-GLAZED THERMALLY-BRIDGED ALUMINUM WINDOWS, REDUCED NATURAL AIR INFILTRATION AND A HEAT RECOVERY VENTILATION SYSTEM (ECM95).
    - Avoided Costs For Energy – ECM95 is not worth doing in most analyzed cases. In the absence of costs due to lost floor area, ECM95 would have yielded positive net benefits in H1 (cost of lost area was $1,233). The break-even point for H1 would have been at 6%.
    - Social Cost Premiums For Energy – ECM95 yielded negative net benefits across the range of discount rates in H2. However, in H1, positive net benefits arose in the 5% and 8% analyses – ECM95 is

worth doing. Break-even turned out to be about 7%. In the absence of reduced floor area, the break-even point for H1 would have been about 8%.

SWITCHING FROM NATURAL GAS TO ELECTRICITY

14. INCORPORATE UPGRADES FROM ITEM 13 (ABOVE) AND REPLACE THE ORIGINAL NATURAL GAS HEATING SYSTEM WITH AN ELECTRIC BASEBOARD SYSTEM (ECM96).
    - Avoided Costs For Energy – In H2, the switch from natural gas heating to electric heating increased net benefits, but they continued to be negative. The fuel switch did, however, result in positive net benefits in H1. Break-even turned out to be between 7% and 8%. In the absence of reduced floor area, the break-even point would have been closer to 9%.
    - Social Cost Premiums For Energy – Social cost premiums increased net benefits overall. In H2, the increase did not generally change results – ECM96 is still not worth doing. However, in the absence of reduced floor area in H2, the result would have been positive net benefits in the 5% discount rate case which makes ECM96 worth adopting. In H1, ECM96 is worth doing up to between 9% and 10% discount rates. In the absence of lost floor area, this upgrade would be worth doing across all discount rates analyzed.
15. SWITCH FROM NATURAL GAS HEATING TO ELECTRIC BASEBOARD HEATING IN THE ORIGINAL, NON-UPGRADED, HOUSE (ECM53).
    - ECM53 yielded positive net benefits in all cases analyzed and is found to be worth doing.

CONCLUSIONS – WILL PROPOSED BUILDING CODE UPGRADES SAVE MONEY?

In a recent press release, the (B.C.) Minister of Energy, Mines and Petroleum Resources announced "new energy efficiency standards ... will help protect the environment and save [money]." These new standards affect residential home construction and include upgrades of insulation in the following components:

- roofs,
- frame and foundation walls,
- suspended floors, and,
- concrete slabs.

Upgrades analyzed in this study are similar to proposed upgrades for the Building Code[12]. At low discount rates, a number of proposed upgrades turned out to be less expensive than building large-scale power generation facilities. However, at high discount rates, most upgrades were not worth adopting. Consumers who make purchase decisions using implicit discount rates of 11 percent and higher[13] would not invest in conservation upgrades. Regulation would therefore be required to achieve higher housing standards.

Whereas a number of upgrades were individually worth adopting, proposed changes to the B.C. Building Code require the combining of a number of different upgrades (B.C. Ministry of Housing 1993). The effects of these proposed changes were analyzed in this study (refer to points 13 and 14 above). Findings suggested that the integrated package of upgrades would be worth adopting, but only in a few cases.

In cases where the integrated package was not worth adopting, the cost of lost floor area was significant in reducing net benefits. According to present practice, maximum floor space is prescribed as a proportion of the property's total area. This is referred to as maximum "floor space ratio".

Exterior house dimensions are used to determine compliance to the maximum floor space ratio. Because home buyers want maximum floor area, builders view upgrades which reduce floor area as reducing the value of the house. In the case of upgrading from 'R12' to 'R40' walls, the cost of reduced floor area was $9,250 for H1, and $10, 938 for H2. Net benefits for an 'R40' upgrade were negative, but, in the absence of these costs, 'R40' walls would have been worth adopting. To encourage adoption of higher standards, the current practice of prescribing maximum floor space ratio on the basis of exterior house dimensions should be changed to use interior dimensions. In this way, builders will not be penalized for building to higher standards.

The upgrade where mechanical heat recovery ventilation was combined with greater air tightness also reduced net benefits of the integrated package. It must be noted, at this point, that benefits to personal health from better indoor air quality (i.e., mechanical ventilation) were not included in this study. As a result, net benefits determined in this study understate the value of mechanical ventilation. Nevertheless, the study's findings point to the possibility that reducing air infiltration and installing heat recovery ventilation may result in a net increase in energy consumption due to fan power requirements.

In general, benefits of new energy efficiency standards were not robust across a range of discount rates, supplier costs and energy costs. This study found that the integrated package of upgrades would not be worth adopting in most of the cases analyzed.

FOOTNOTES

[1] A natural gas system requires gas piping and accessories, a gas flue, and ductwork. Also, regular maintenance is required. Electric baseboard heating requires only that the baseboard units be put in place, and properly wired. Maintenance is generally not required on baseboards. Refer to appendix B for detailed costs.

FOOTNOTES ...

2 Incremental maintenance costs were not adjusted. Only initial costs were changed for sensitivity analysis.

3 ECM95 was introduced to analyze the performance of integrating several upgrades.

4 This compares with H1 in which net savings for ECM41 were positive.

5 Insulation values for the six window upgrades are presented in appendix D.

6 Only two of the five can be considered upgrades.

7 Of the three houses in the study, houses H1 and H2 were analyzed in all upgrades. Because TH1 was already built to higher standards, it was analyzed in the windows upgrades analyses.

8 Recall that house H1 is a two-level house built on a concrete slab foundation. A spark ignition natural gas furnace provides space heating. House H2 is a two-level house built on an unheated crawl space foundation. Space heating is provided by both a spark ignition natural gas furnace and a number of electric resistance baseboard heaters, Insulation in H1 and H2 was installed according to pre-1990 Building Code standards. In addition to these houses, house TH1 was also analyzed. TH1 is a three-level townhouse built on a concrete slab foundation. Electric baseboard heaters provide the space heating. Insulation in TH1 was installed according to R2000 standards. TH1 was only analyzed for window upgrades.

9 In TH1, ECM31, 32 and 33 were downgrades, and ECM35 and 36 were upgrades. Energy consumption increases as a result of a window downgrade. Net savings are negative. However, supplier cost for a downgrade is less than the existing window. Net costs are also negative. In TH1, supplier cost savings were sometimes greater than increases in electricity bills which resulted in positive net benefits.

10 The insulation value of ECM33 is lower than existing triple-glazed windows. As a result, lower discount rates will value the long term incremental cost of choosing ECM33 more than higher discount rates.

11 That is, H1, H2 and TH1.

12 In arriving at the proposed upgrades for the B.C. Building Code, three criteria had to be satisfied (B.C. Ministry of Housing 1993):

i. Cost effectiveness – financial benefits from an energy standard should equal or exceed the capital costs of the additional energy efficiency measures;
ii. Affordability – compared to the 1992 energy standard, the (new) recommended standard did not result in a significant difference between an owner's ability to purchase and meet monthly carrying costs; and,
iii. Technical feasibility – the recommended energy standard had to be practical, easy to understand and administer, and flexible (to builders).

Cost effectiveness calculations differed from the methodology used in 'Save The Crown Joules'. Whereas long term costs and benefits of recommended energy standards were discounted to the present, single point estimates were used to estimate discount

FOOTNOTES ...

rate (6% was used), supplier costs and energy costs. Furthermore, two other significant differences arose in estimating supplier costs: lost floor area costs were not included, and mechanical ventilation was not included. Consequently, results from the Ministry of Housing's study should not be directly compared with results from 'Save The Crown Joules'.

13 See Richards and Sims 1989; Hausman and Joskow 1982, p. 221; Dubin and McFadden 1980.

APPENDIX A

Details Of Construction Standards

Appendix A lists construction standards for the houses used in this study. Exhibit A.1 lists the component standards before upgrades. Standards for conventionally built houses, and for R2000 built townhouses have been provided. Exhibits A.2 and A.3 describe the upgrades for analysis.

Exhibit A.1 Minimum construction standards for houses used in this study.

COMPONENT	COMPONENT STANDARD IN CONVENTIONALLY BUILT HOUSES	COMPONENT STANDARD IN 'R2000' TOWNHOUSES
Exterior walls	Insulation level R12.	Insulation level R20.
Attic ceilings, vaulted ceilings, and over-hanging floors	Insulation level R28.	Insulation level R40.
Concrete foundations – below grade walls, slab edges, and slab floors	No insulation – effective insulation level, R1.1.	Insulated to R8 at slab edge, and for 3 feet depth along slab perimeter.
Glazing – windows, patio doors, skylights, etc.	Double glazed, solid aluminum frame (i.e., no thermal bridging), $\frac{1}{2}$ inch air space – effective insulation level, R1.1 to R1.6.	Triple glazed, thermally bridged aluminum frame – effective insulation level, 2.0 to 2.7. Sliding windows were double glazed – effective insulation level, R1.7.
Ventilation	Continuous mechanical ventilation not provided, however bathroom and kitchen exhaust fans have been installed.	Heat recovery ventilator operating at 0.55 air changes per hour.
Heating system – forced air, natural gas furnace	78% efficient, spark ignition furnace.	Not applicable.
Heating system – electric baseboard	100% efficient.	100% efficient.

APPENDIX A

Exhibit A.2 Details for each Energy-Conserving Measures (ECM).

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM00	n.a.	Existing house parameters (refer to appendix U).
ECM11	20	Walls from R12 to R20 using 2X6 wood stud construction.
	4.5	Doors from R3.6 to R4.5 using insulated doors.
ECM12	40	Walls from R12 to R40 standard using 2X6 and double studded wall construction.
	8	Doors from R3.6 to R8 using insulated doors.
ECM21	40	Attics & floor overhangs from R28 to R40 using blown-in cellulose insulation.
ECM22	8.5	Place 2-inch rigid insulation under slab including perimeter.
	8.5	Insulate slab edge – assume a .3 meter width of rigid insulation.
ECM23	6	Blown-in cellulose on all interior surfaces of basements & crawl spaces (and glue compound).
ECM31		Replace existing windows with double-glazed (DG) windows and thermally-bridged aluminum (TB) frames.
ECM32		Replace existing windows with DG windows and vinyl frames.
ECM33		Replace existing windows with DG windows and argon air space, and TB frames.
ECM34		Replace existing windows with triple-glazed windows and TB frames.
ECM35		Replace existing windows with DG windows and low-e film, and vinyl frames (e = 0.2).
ECM36		Replace existing windows with DG window and low-e film, insulated spacer, and TB frames (a.k.a. Heat Mirror® 66)

APPENDIX A

Exhibit A.3 Details for each Energy-Conserving Measures (ECM).

ECM	TARGET 'R'	COMPOSITION OF ECM UPGRADES RELATIVE TO STANDARD CONSTRUCTION
ECM41		Employ air-tight construction (Advanced Drywall Approach). Heat recovery ventilator. Add 0.8 kWh/day to Base Loads as estimate of half-year operation of HRV.
ECM51		Replace existing heating system with a natural gas furnace of efficiency 78 percent. Decrease capacity from 75MBTU to 60MBTU.
ECM52		Replace existing heating system with a natural gas condenser furnace of steady-state efficiency 94 percent. Decrease capacity from 75MBTU to 40MBTU.
ECM53		SWITCH FUEL SOURCE TO ELECTRICITY - Replace existing heating system with electric radiant baseboard heaters of effective efficiency 100 percent. Do not change Base Loads 2.4 kWh/day figure. Subtract the original installed cost of a 65%-eff. gas furnace.
		INTEGRATED UPGRADES -
ECM95		Combine ECMs 11, 21, 22, 41, 52. Fuel source: NATURAL GAS.
ECM96		Combine ECMs 11, 21, 22, 41, 53 (as per R2000 house). Fuel source: ELECTRICITY.

APPENDIX B

Detailed Costs Of Upgrades

Appendix B illustrates techniques used to determine costs for upgrades. Costs for upgrades to the building envelope have been summarized into unit costs such as dollars per square foot ($/s.f.). Costs for upgrades involving heating systems and ventilation equipment have been provided as system costs. That is, the cost to upgrade to a 99 percent efficient, condenser gas furnace includes equipment and installation costs for the furnace, accompanying duct work, piping and gas valve, and controls. Costs for window upgrades were calculated on a house by house basis. This was done because some window suppliers did not provide general guidelines for estimating costs, but instead, chose to estimate each window individually. Results for envelope upgrades and heating system upgrades have been tabulated and presented below. Costs for window upgrades have been presented separately (at the end of appendix B) on a house-by-house basis.

APPENDIX B

Exhibit B.1 Detailed upgrade costs for energy conservation measures (ECMs).

ECM11 – INCREASE WALL INSULATION TO R20.		
Increase insulation via batt or blown-in methods.	Estimates of incremental unit costs ranged from 10.3 cents to 16.1 cents per square feet of wall area.	15¢/s.f.
Use two-by-six studs spaced at either 16 inch or 24 inch centers.	Estimates of incremental unit costs ranged from 0.0 cents to 45 cents per square feet of wall area. If 24 inch spacing were used, then the upgrade would not incur additional cost.	20¢/s.f.
Increase door insulation from R3.6 to R4.5.	Incremental upgrade cost per door, approximately $36.	$36 per door
Cost of lost floor area	Market estimates, $50 per square foot lost area. In H1, lost floor area cost ($1,233). In H2, lost floor area cost ($1,459).	$50/s.f. lost area
	TOTAL INCREMENTAL UNIT COST	35¢/s.f. wall area $36 per door $50/s.f. lost area
ECM12 – INCREASE WALL INSULATION TO R40		
Increase insulation via batt or blown-in methods.	Estimates of incremental unit costs ranged from 38.7 cents to 58.5 cents per square feet of wall area.	57¢/s.f.
Use "double two-by-six" studs technique.	Estimate of incremental unit costs was found to be 80 cents per square foot of wall area.	80¢/s.f.
Increase door insulation from R3.6 to R4.5.	Incremental upgrade cost per door, approximately $36.	$36 per door
Cost of lost floor area	Market estimates, $50 per square foot lost area. In H1, lost floor area cost ($9,250). In H2, lost floor area cost ($10,938).	$50/s.f. lost area
	TOTAL INCREMENTAL UNIT COST	$1.35/s.f. wall area $36 per door
ECM21 – INCREASE ATTIC INSULATION FROM R28 TO R40		
Increase added insulation via blown-in method. Leave vaulted ceiling insulation unchanged at R28.	Estimates of incremental unit costs ranged from 16.6 cents to 28 cents per square feet of wall area.	23¢/s.f.
	TOTAL INCREMENTAL UNIT COST	23¢/s.f. wall area

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ECM22 – PROVIDE EXTERIOR INSULATION FOR FOUNDATIONS		
Provide R8 insulation for concrete foundations using $1\frac{1}{2}$ inch rigid insulation (i.e., above and below grade walls, slab edge, and on under side of slab).	Based on \$8.50 for a 16 square foot board of rigid insulation, unit cost came to 53 cents per square feet.	53¢/s.f.
	TOTAL INCREMENTAL UNIT COST	53¢/s.f. of total wall, and slab area.
ECM23 – PROVIDE INTERIOR INSULATION FOR CRAWL SPACES AND BASEMENTS		
Provide blown-in insulation for walls, under side of floor, and top of slab. Insulation value to be R6.	Cost to provide blown-in insulation complete with glue compound, 23 cents per square feet of total surface area.	23¢/s.f.
	TOTAL INCREMENTAL UNIT COST	23¢/s.f. of total wall, floor, and slab area
ECM31 to ECM36 – window upgrades are shown separately after ECM53.		
ECM41 – REDUCE NATURAL AIR INFILTRATION AND INSTALL HEAT RECOVERY VENTILATOR		
Use "Advanced Drywall Approach" instead of standard vapour barrier method to achieve air tightness[1].	Incremental cost to use Advanced Drywall Approach, 71 cents per square feet for walls, and floor joists and headers; 75 cents per square feet for attics.	75¢/s.f. for attics 71¢/s.f. for wall and floor areas
Provide heat recovery ventilator (capacity flow rate up to 140 cubic feet per minute, cfm), and duct work.	Cost to provide HRV and duct work, approximately \$2,080 for houses used in this study (i.e., up to 7 rooms served by HRV).	\$2,080 per house
	TOTAL INCREMENTAL UNIT COST	75¢/s.f. for attics 71¢/s.f. for wall and floor areas \$2,080 per HRV
ECM51 – INCREASE EFFICIENCY OF GAS FURNACE FROM 65% TO 78%		
Upgrade the existing 65% efficient natural gas furnace to 78% efficiency. As a result, decrease capacity from 75MBTU to 60MBTU.	Incremental cost to upgrade the furnace, \$430. Incremental maintenance costs include replacing, • gas valve every 20 years, \$100; • controls every 10 years, \$210.	\$430 for furnace every 25 years \$100 per gas valve every 20 years \$210 for controls every 10 years

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ECM52 – INCREASE EFFICIENCY OF GAS FURNACE FROM 65% TO 99%		
Upgrade the existing 65% efficient natural gas fumace to 94% efficiency. As a result, decrease capacity from 75MBTU to 40MBTU.	Incremental cost to upgrade the furnace, $1,200. Incremental maintenance costs include replacing, • gas valve every 20 years, $100; • controls every 10 years, $210; • power venter every 10 years, $250.	$1,200 for furnace every 25 years $100 for gas valve every 20 years $460 for controls and power venter every 10 years

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ECM53 – REPLACE GAS FURNACE HEATING WITH ELECTRIC BASEBOARD HEATING		
Replace existing 65% efficient natural gas furnace with electric radiant baseboard heaters of effective efficiency 100%.	Cost to provide baseboard heaters, 50 cents per square feet of floor area. Figure is based on equipping a 1,500 square foot house.	50¢/s.f. floor area
Cost of lost floor area	Market estimates, $50 per square foot lost area.	$50/s.f. lost area

Sample calculations:
To determine the cost of upgrading to ECM53, the total installed cost of a 65%efficient gas furnace system was subtracted from the total installed cost of a baseboard system in the following ways ...

For house 'H1'	(1) INITIAL UPGRADE COST Credit from re-acquired floor area: ($300) Cost to provide baseboard heaters: $1,069 Cost to provide gas furnace heating: minus $2,000 Initial cost of upgrade ($1231)	Initial upgrade cost: ($1231)
	(2) SAVINGS ARISING FROM AVOIDED MAINTENANCE COSTS: • heat exchanger every 25 years, $800; • gas valve every 20 years, $150; • blower motor every 10 years, $250;	Maintenance costs: ($800) every 25 yr ($150) every 20 yr ($250) every 10 yr
For house 'H2'	(1) INITIAL UPGRADE COST Credit from re-acquired floor area: ($300) Cost to provide baseboard heaters: $1,197 Cost to provide gas furnace heating: minus $2,000 Initial cost of upgrade ($1103)	Initial upgrade cost: ($1103)
	(2) SAVINGS ARISING FROM AVOIDED MAINTENANCE COSTS: • heat exchanger every 25 years, $800; • gas valve every 20 years, $150; • blower motor every 10 years, $250;	Maintenance costs: ($800) every 25 yr ($150) every 20 yr ($250) every 10 yr

APPENDIX B

UPGRADE COSTS FOR WINDOWS AND OTHER GLAZING

Exhibit B.2 Window upgrade costs for house 'H1'.

TYPE OF UPGRADE	ECM31	EMC32	ECM33	ECM34	ECM35	ECM36
WINDOW TYPE • Picture window. • Al-frame originally not thermally bridged. • Total area = 86 sq. ft. • Original cost = $605.						
Additional cost:	$194	$254	$245	$387	$593	$1,032
• Sliding window. • Al-frame originally not thermally bridged. • Total area = 54 sq. ft. • Original cost = $860.						
Additional cost:	$318	$370	$462	$482	$860	$648
Total cost to upgrade all windows in the house:	$512	$624	$708	$869	$1,453	$1,680

Values shown represent the difference in cost to upgrade existing windows. Windows were originally double glazed.

APPENDIX B

Exhibit B.3 Window upgrade costs for house 'H2'.

TYPE OF UPGRADE	ECM31	EMC32	ECM33	ECM34	ECM35	ECM36
WINDOW TYPE						
• Picture window. • Al-frame originally not thermally bridged. • Total area = 152 sq. ft. • Original cost = $1,138.						
Additional cost:	$364	$478	$455	$728	$1,115	$1,824
• Hinged window. • Al-frame originally not thermally bridged. • Total area = 38 sq. ft. • Original cost = $732.						
Additional cost:	$271	$615	$294	$410	$820	$456
• Sliding window. • Al-frame originally not thermally bridged. • Total area = 89 sq. ft. • Original cost = $707.						
Additional cost:	$262	$304	$407	$396	$707	$1,068
Total cost to upgrade all windows in the house:	$897	$1,397	$1,156	$1,534	$2,642	$3,348

Values shown represent the difference in cost to upgrade existing windows. Windows were originally double glazed.

APPENDIX B

Exhibit B.4 Window upgrade costs for house 'TH1'. Values shown represent the difference in cost to upgrade existing windows. Windows were originally triple glazed.

TYPE OF UPGRADE	ECM31	EMC32	ECM33	ECM34	ECM35	ECM36
WINDOW TYPE						
• Picture window. • Al-frame originally thermally bridged. • Total area = 68 sq. ft. • Original cost = $424.						
Additional cost:	($136)	($93)	($95)	$0	$144	$545
• Hinged window. • Al-frame originally not thermally bridged. • Total area = 71 sq. ft. • Original cost = $845.						
Additional cost:	($161)	$237	($118)	$0	$473	$379
• Sliding window. • Al-frame originally not thermally bridged. • Total area = 89 sq. ft. • Original cost = $634.						
Additional cost:	($120)	($82)	$15	$0	$279	$713
Total cost to upgrade all windows in the house:	($417)	$61	($197)	$0	$896	$1,636

FOOTNOTES

1 ADA can achieve air tightness of 2 air changes per hour (2 ACH) when tested at a pressure of 50 pascals. ADA provides a vapour barrier around the house envelope with special attention paid to insulating and sealing "box joists" (i.e., the floor joint), protrusions through the house envelope (i.e., electrical conduits, plumbing pipes and vents), and windows.

APPENDIX C

Results of HOT2000 Validation Tests

HOT2000 is a computer program that estimates space heating loads for housing. This study compared estimated heating loads with actual consumption for the three houses used in the upgrades analysis. Results of HOT2000 validation tests are presented.

Exhibits C.1 to C.3 present HOT2000 estimates for different upgrades. In ECM00 (ECM stands for energy-conserving measure), the house was analyzed before upgrades were adopted. Actual energy consumption figures are presented in exhibits C.4 to C.6. These figures were obtained from monthly energy bills.

Figures for 'Estimated (Annual) Space Heating' differ considerably between HOT2000 estimates and actual consumption. They are,

- In H1, HOT2000 estimated 25,680 kilowatt-hours for annual space heating. Actual consumption was estimated to be 12,696 kilowatt-hours.
- In H2, HOT2000 estimated 18,595 kilowatt-hours. Actual consumption was estimated to be 15,158 kilowatt-hours.
- In TH1, HOT2000 estimated 4,206 kilowatt-hours. Actual consumption was estimated to be 8,682 kilowatt-hours.

Several factors may have caused such large errors in HOT2000 estimates. The most likely ones are,

- Accurate records of indoor set point temperatures were not available. A one degree (Celsius) change in the indoor average temperature can result in greater than a 10 percent change in heating load[1].
- Electricity used in heating was not separated from other electrical uses. Similarly, natural gas used in heating was not separated from other gas uses. To estimate the proportion of energy used for heating in each

APPENDIX C

house, summer monthly energy consumption formed a base consumption level. Monthly consumption exceeding this base level was attributed to heating.

- Most of the occupants frequently used fireplaces. Occupants of the three conventionally built houses used their fireplaces several times each week. Since HOT2000 does not simulate the effects of fireplace use on space heating[2], frequent fireplace use will increase the error of HOT2000 estimates.

In the absence of specific energy consumption data, it was difficult to validate the accuracy of HOT2000 in this study. Experts who regularly use HOT2000 to estimate heating loads warned of inaccuracies arising from fireplace use (both open and enclosed fireplaces), large south-facing window areas (over-heating rooms), and lack of temperature monitoring equipment.

In addition, actual heating records were only available for a one year period. In that same year, average monthly temperatures in the Lower Mainland of B.C. were significantly higher than historical monthly averages[3]. To adjust for these changes, HOT2000's built-in weather records (data gathered over a ten-year period) were not used in the validation analysis. A new weather file was created for reference. It consisted of average monthly temperatures for the twelve months coinciding with heating records.

These sources of error were minimized in the upgrades analyses. Fireplaces were modelled as unused. The indoor setpoint temperature was established as 22 degrees Celsius. HOT2000's built-in weather records were used.

APPENDIX C

Exhibits C.1 to C.3 present HOT2000 estimates for different upgrades.

ECM00 represents house conditions before upgrading.

Exhibit C.1 HOT2000 estimates for H1.

	ECM00	ECM11	ECM12	ECM21	ECM22	ECM31	ECM32
Estimated Space Heating (kWh/yr)	25680.2	21554.9	18514.3	24798.8	22715.4	24036.5	23522.4
(GJ/yr)	92.449	77.598	66.651	89.276	81.775	86.531	84.681
Ventilator Consumption (kWh/yr)	34.4	34.4	34.4	34.4	34.4	34.4	34.4
(GJ/yr)	0.124	0.124	0.124	0.124	0.124	0.124	0.124
Estimated DHW Heating (kWh/yr)	8352.1	8352.1	8352.1	8352.1	8352.1	8352.1	8352.1
(GJ/yr)	30.068	30.068	30.068	30.068	30.068	30.068	30.068
Combined Space & DHW (kWh/yr)	34066.8	29941.4	26900.8	33185.3	31101.9	32423	31908.9
(GJ/yr)	122.64	107.789	96.843	119.467	111.967	116.723	114.872
R2000 Target (kWh/yr)	17385.3	17385.3	17385.3	17385.3	17385.3	17385.3	17385.3
(GJ/yr)	62.587	62.587	62.587	62.587	62.587	62.587	62.587
Total L&A Consumption (kWh/yr)	9782	9782	9782	9782	9782	9782	9782
Incremental Electricity Consumption (kWh/yr)	n/a	0	0	0	0	0	0
Incremental Gas Consumption (kWh/yr)	n/a	-4125.3	-7165.9	-881.4	-2,965	-1,644	-2,158
(GJ/yr)	n/a	-14.851	-25.798	-3.173	-10.674	-5.918	-7.768

'L&A' = lighting and appliances; 'DHW' = domestic hot water.

APPENDIX C

Exhibit C.1 HOT2000 estimates for H1 (continued).

	ECM33	ECM34	ECM35	ECM36	ECM41	ECM52	ECM53
Estimated Space Heating (kWh/yr)	23785.1	25059.8	22673.1	22976.4	23098.6	17937.6	17031.8
(GJ/yr)	85.626	90.215	81.623	82.715	83.155	64.575	61.314
Ventilator Consumption (kWh/yr)	34.4	34.4	34.4	34.4	544.8	34.4	34.4
(GJ/yr)	0.124	0.124	0.124	0.124	1.961	0.124	0.124
Estimated DHW Heating (kWh/yr)	8352.1	8352.1	8352.1	8352.1	8352.1	8352.1	8352.1
(GJ/yr)	30.068	30.068	30.068	30.068	30.068	30.068	30.068
Combined Space & DHW (kWh/yr)	32171.7	33446.3	31059.6	31362.9	31995.5	26324.1	25418.3
(GJ/yr)	115.818	120.407	111.815	112.906	115.184	94.767	91.506
R2000 Target (kWh/yr)	17385.3	17385.3	17385.3	17385.3	17385.3	17385.3	15806.3
(GJ/yr)	62.587	62.587	62.587	62.587	62.587	62.587	56.903
Total L&A Consumption (kWh/yr)	9782	9782	9782	9782	9782	9782	9782
Incremental Electricity Consumption (kWh/yr)	0	0	0	0	510	0	0
Incremental Gas Consumption (kWh/yr)	-1,895	-620	-3,007	-2,704	-2,582	-7,743	-8,648
(GJ/yr)	-6.823	-2.234	-10.826	-9.734	-9.294	-27.874	-31.135

'L&A' = lighting and appliances; 'DHW' = domestic hot water.

APPENDIX C

Exhibit C.1 HOT2000 estimates for H1 (continued).

	ECM95	ECM96
Estimated Space Heating (kWh/yr)	8157.1	7797.2
(GJ/yr)	29.366	28.07
Ventilator Consumption (kWh/yr)	544.8	544.8
(GJ/yr)	1.961	1.961
Estimated DHW Heating (kWh/yr)	8352.1	8352.1
(GJ/yr)	30.068	30.068
Combined Space & DHW (kWh/yr)	17054	16694.1
(GJ/yr)	61.394	60.099
R2000 Target (kWh/yr)	17385.3	15806.3
(GJ/yr)	62.587	56.903
Total L&A Consumption (kWh/yr)	9782	9782
Incremental Electricity Consumption (kWh/yr)	510	510
Incremental Gas Consumption (kWh/yr)	-17,523	-17,883
(GJ/yr)	-63.083	-64.379

'L&A' = lighting and appliances;
'DHW' = domestic hot water.

APPENDIX C

Exhibit C.2 HOT2000 estimates for H2.

	ECM00	ECM11	ECM12	ECM21	ECM22	ECM23	ECM31
Estimated Space Heating (kWh/yr)	18595.2	14871.9	12492.7	18019.2	18248.1	18156.4	16945.2
(GJ/yr)	66.943	53.539	44.974	64.869	65.693	65.363	61.003
Ventilator Consumption (kWh/yr)	33.9	33.9	33.9	33.9	33.9	33.9	33.9
(GJ/yr)	0.122	0.122	0.122	0.122	0.122	0.122	0.122
Estimated DHW Heating (kWh/yr)	12018.9	12018.9	12018.9	12018.8	12018.9	12018.8	12018.8
(GJ/yr)	43.268	43.268	43.268	43.268	43.268	43.268	43.268
Combined Space & DHW (kWh/yr)	30647.9	26924.7	24545.5	30072	30300.9	30209.2	28997.9
(GJ/yr)	110.333	96.929	88.364	108.259	109.083	108.753	104.393
R2000 Target (kWh/yr)	17023.7	17023.7	17023.7	17023.7	17023.7	17023.7	17023.7
(GJ/yr)	61.285	61.285	61.285	61.285	61.285	61.285	61.285
Total L&A Consumption (kWh/yr)	8395	8395	8395	8395	8395	8395	8395
Incremental Electricity Consumption (kWh/yr)	n/a	0	0	0	0	0	0
Incremental Gas Consumption (kWh/yr)	n/a	-3,723	-6,103	-576	-347	-439	-1,650
(GJ/yr)	n/a	-13.404	-21.969	-2.074	-1.25	-1.58	-5.94

'L&A' = lighting and appliances; 'DHW' = domestic hot water.

APPENDIX C

Exhibit C.2 HOT2000 estimates for H2 (continued).

	ECM32	ECM33	ECM34	ECM35	ECM36	ECM41	ECM52
Estimated Space Heating (kWh/yr)	15650.1	16666.4	15073.3	14627.9	15040.1	18517.1	13188
(GJ/yr)	56.34	59.999	54.264	52.66	54.144	66.662	47.477
Ventilator Consumption (kWh/yr)	33.9	33.9	33.9	33.9	33.9	536.4	33.9
(GJ/yr)	0.122	0.122	0.122	0.122	0.122	1.931	0.122
Estimated DHW Heating (kWh/yr)	12018.8	12018.8	12018.9	12018.8	12018.8	12018.8	12018.9
(GJ/yr)	43.268	43.268	43.268	43.268	43.268	43.268	43.268
Combined Space & DHW (kWh/yr)	27702.8	28719.1	27126	26680.6	27092.9	31072.4	25240.8
(GJ/yr)	99.73	103.389	97.654	96.05	97.534	111.861	90.867
R2000 Target (kWh/yr)	17023.7	17023.7	17023.7	17023.7	17023.7	17023.7	17023.7
(GJ/yr)	61.285	61.285	61.285	61.285	61.285	61.285	61.285
Total L&A Consumption (kWh/yr)	8395	8395	8395	8395	8395	8395	8395
Incremental Electricity Consumption (kWh/yr)	0	0	0	0	0	503	0
Incremental Gas Consumption (kWh/yr)	-2,945	-1,929	-3,522	-3,967	-3,555	-78	-5,407
(GJ/yr)	-10.603	-6.944	-12.679	-14.283	-12.799	-0.281	-19.466

'L&A' = lighting and appliances; 'DHW' = domestic hot water.

APPENDIX C

Exhibit C.2 HOT2000 estimates for H2 (continued).

	ECM53	ECM95	ECM96
Estimated Space Heating (kWh/yr)	12714.7	7885.4	7457.4
(GJ/yr)	45.773	28.387	26.847
Ventilator Consumption (kWh/yr)	33.9	33.9	33.9
(GJ/yr)	0.122	0.122	0.122
Estimated DHW Heating (kWh/yr)	12018.9	12018.9	12018.9
(GJ/yr)	43.268	43.268	43.268
Combined Space & DHW (kWh/yr)	24767.5	19938.1	19510.1
(GJ/yr)	89.163	71.777	70.237
R2000 Target (kWh/yr)	15516.9	17023.7	15516.9
(GJ/yr)	55.861	61.285	55.861
Total L&A Consumption (kWh/yr)	8395	8395	8395
Incremental Electricity Consumption (kWh/yr)	0	0	0
Incremental Gas Consumption (kWh/yr)	-5,881	-10,710	-11,138
(GJ/yr)	-21.17	-38.556	-40.096

'L&A' = lighting and appliances;
'DHW' = domestic hot water.

APPENDIX C

Exhibit C.3 HOT2000 estimates for TH1.

	ECM00	ECM31	ECM32	ECM33	ECM35	ECM36
Estimated Space Heating (kWh/yr)	4206.4	4780	4232.4	4589.7	3509.1	3158.8
(GJ/yr)	15.143	17.208	15.237	16.523	12.633	11.372
Ventilator Consumption (kWh/yr)	1117.5	1117.5	1117.5	1117.5	1117.5	1117.5
(GJ/yr)	4.023	4.023	4.023	4.023	4.023	4.023
Estimated DHW Heating (kWh/yr)	5125.6	5125.6	5125.6	5125.6	5125.6	5125.6
(GJ/yr)	18.452	18.452	18.452	18.452	18.452	18.452
Combined Space & DHW (kWh/yr)	10449.4	11023	10475.5	10832.7	9752.2	9401.9
(GJ/yr)	37.618	39.683	37.712	38.998	35.108	33.847
R2000 Target (kWh/yr)	9761.6	9761.6	9761.6	9761.6	9761.6	9761.6
(GJ/yr)	35.142	35.142	35.142	35.142	35.142	35.142
Total L&A Consumption (kWh/yr)	9271	9271	9271	9271	9271	9271
Incremental Electricity Consumption (kWh/yr)		0	0	0	0	0
Incremental Gas Consumption (kWh/yr)		574	26	383	-697	-1,048
(GJ/yr)		2.065	0.094	1.38	-2.51	-3.771

'L&A' = lighting and appliances; 'DHW' = domestic hot water.

APPENDIX C

Exhibits C.4 to C.6 present energy consumption figures from monthly billing records. Accompanying these figures, sample calculations have been provided to illustrate the methodology used in estimating energy consumption for heating.

In H1, natural gas is used in space heating and hot water heating. Using summer daily gas consumption as a base, space heating load can be estimated by the excess daily gas consumption during the remaining months of the year.

In H2, both natural gas and electricity are used in providing space heat. A similar methodology to H1 can be used in estimating gas space heating load in H2. Likewise, electric space heating load can be estimated by the excess consumption of electricity over the summer daily electricity load. Annual space heating load is therefore the sum of gas and electricity space heating loads.

Space heating in TH1 is provided primarily by electric baseboard heaters. To estimate annual electric space heating load in TH1, a similar approach to determining H2 electric space heating load is used. In addition, operating the gas fireplace contributes to space heating. Since the fireplace is the only gas burning appliance, total gas consumption can be considered part of space heating.

APPENDIX C

Exhibit C.4 Monthly billing records for H1.

ELECTRICITY			GAS		
	DATE	kWh		DATE	GJ
	8/Jun/92	1628.0		8/Jun/92	13.400
	3/Apr/92	1443.0		3/Apr/92	17.600
	6/Feb/92	2785.0		6/Feb/92	29.500
	7/Dec/91	1468.0		7/Dec/91	22.700
	9/Oct/91	1368.0		9/Oct/91	7.600
	9/Aug/91	1412.0	<summer base>	9/Aug/91	8.900
	10/Jun/91			10/Jun/91	

Exhibit C.4 Sample load calculations for H1.

LIGHTING & APPLIANCES LOAD: Using Electricity Only		SPACE HEATING LOAD: Using natural gas only	
Total Electricity (kWh):	10104	Total Gas (GJ):	99.700
Total Days:	364	Total Days:	364
Electric Load (kWh/day):	27.8	Gas Load (GJ/day):	0.274
		Summer Consumption (GJ):	8.9
		Total Summer Days:	60
		Summer Gas Load (GJ/day):	0.148
		Annual Gas Load For Non-Heating Use (GJ): i.e., 365 days x Summer Base	53.993
		Estimated Annual Space Heating Load (GJ): i.e., Total Gas – Annual Gas Load For Non-Heating Use	45.707
		Estimated Annual Space Heating Load (kWh):	**12,696**

Spec's - Gas: Used in space heating, DHW.
Electricity: Used in lights & appliances (L&A).

APPENDIX C

Exhibit C.5 Monthly billing records for H2.

ELECTRICITY	DATE	kWh	GAS	DATE	GJ
	5/May/92	1221.0		5/May/92	13.700
	5/Mar/92	1902.0		5/Mar/92	23.900
	8/Jan/92	3622.0		8/Jan/92	30.700
	9/Oct/91	846.0		9/Oct/91	4.600
<summer base>	9/Aug/91	778.0	<summer base>	9/Aug/91	6.200
<summer base>	10/Jun/91	623.0	<summer base>	10/Jun/91	6.700
	26/Apr/91			26/Apr/91	

Exhibit C.5 Sample load calculations for H2.

ELECTRIC BASEBOARD, LIGHTING & APPLIANCES LOADS: Using Electricity Only		GAS LOAD FOR SPACE & HOT WATER HEATING:	
Total Electricity (kWh):	8992.0	Total Gas (GJ):	85.800
Total days:	375	Total days:	375
Electric Load (kWh/day):	24.0	Gas Load (GJ/day):	0.229
Summer Electricity Consumption (kWh):	1401.0	Summer Gas Consumption (GJ):	12.900
Summer days:	105	Summer days:	105
Summer Electric Load (kWh/day):	13.3	Summer Gas Load (GJ/day):	0.123
L & A Annual Load (kWh): i.e., 365 days x Summer Electric Load	4870.1	Hot Water Heating Load (GJ): i.e., 365 days x Summer Gas Load	46.071
Estimated Annual Baseboard Heating (kWh): i.e., Total Electricity – L & A Annual Load	4121.9	Estimated Annual Gas Heating Load (GJ):	39.729
		Estimated Annual Gas Heating Load (kWh):	11036

TOTAL SPACE HEATING LOAD:				
Estimated Annual Space Heating (GJ): i.e., Baseboard & Gas Combined	54.6	OR	**Estimated Annual Space Heating (kWh):**	**15,158**

Spec's - Gas: Space heating, DHW.
Electricity: Lights & appliances (L&A), baseboard heating (bsbd).

APPENDIX C

Exhibit C.6 Monthly billing records for TH1.

ELECTRICITY			GAS	
	DATE	kWh	DATE	GJ
	9/Oct/92	1439.0	9/Oct/92	1.800
<summer base>	12/Aug/92	1390.0	12/Aug/92	1.800
<summer base>	11/Jun/92	1968.0	11/Jun/92	2.900
	7/Apr/92	2167.0	7/Apr/92	5.400
	10/Feb/92	2357.0	10/Feb/92	8.700
	10/Dec/91	2067.0	10/Dec/91	4.400
	10/Oct/91		10/Oct/91	

Exhibit C.6 Sample load calculations for TH1.

ELECTRIC BASEBOARD, LIGHTING AND APPLIANCE LOAD:			NATURAL GAS CONSUMPTION	
Total Electricity (kWh):	11388			
Total days:	365			
Total Electric Load (kWh/day):	31.2		Natural Gas Consumption (GJ):	25.000
Summer Electric Load (kWh):	3358.0		Natural Gas Consumption (kWh):	6944.4
Summer days:	127			
Summer Electric Load (kWh/day):	26.4			
Total Non-Heating Electric Load(kWh): i.e., 365 days x Summer Electric Load	9650.9			
Estimated Electricity Space Heating Load (kWh): i.e., Total Electricity – Total Non-Heating Load	1737.1			
Estimated Annual Space Heating (kWh): i.e., Electricity Space Heating + Gas Consumption	**8681.5**	OR	Estimated Annual Space Heating (GJ):	31.3

Spec's - Gas: Space heating, DHW.
Electricity: Lights & appliances (L&A), baseboard heating (bsbd).

FOOTNOTES

1 This was suggested while in conversation with HOT2000 users. In testing this suggestion, several heating load estimates were re-analyzed using a one degree change in setpoint temperature. Results supported the claim that HOT2000 estimates change by 10% for a one degree change in indoor temperature.

APPENDIX C

FOOTNOTES ...

[2] This was suggested while in conversation with HOT2000 users. Regular use of fireplaces that are not sealed (i.e. are not enclosed and equipped with intake and exhaust flues) will significantly change heating loads. Even if fireplaces are sealed (i.e. with glass doors), some HOT2000 experts warn that heat conduction through glass, and metal frames, may increase heating loads by 15 percent or more.

[3] Environment Canada officials estimated winter monthly averages to be approximately 1.5 degrees higher than normal. In the Lower Mainland, this can reduce heating requirements by close to 10 percent.

APPENDIX D

RANKING INSULATION VALUES OF DIFFERENT WINDOW TECHNOLOGIES

In this appendix, different window technologies are ranked. I present the results of the HOT2000 energy modelling computer program.

HOT2000 was used to analyze insulation values of different window technologies. For a specified window type, the unit of measure 'R' will change depending on the area of the window. Since the purpose here is to illustrate relative differences in window insulation, two window sizes were used in the analysis. Results for these two cases have been presented in exhibit D.1.

APPENDIX D

Exhibit D.1 Relative insulation ranking for different windows (1 = greatest insulation).

WINDOW SIZE	5 SQUARE FEET		25 SQUARE FEET		
	R-value	Ranking	R-value	Ranking	Final Ranking[1]
ECM31: Double glazed window, 0.5 inch air space, thermally bridged aluminum frame.	1.49	6	1.82	6	4th score = 12
ECM32: Double glazed window, 0.5 inch air space, vinyl frame.	1.92	3	2.05	4	2nd score = 7
ECM33: Double glazed window, 0.5 inch argon air space, thermally bridged Al-frame.	1.54	5	1.90	5	3rd score = 10
ECM34: Triple glazed windows, 0.5 inch air space, thermally bridged Al-frame.	1.81	4	2.50	3	2nd score = 7
ECM35: Double glazed window, 0.5 inch air space, low e film (e=0.2), vinyl frame.	2.23	1	2.60	2	1st score = 3
ECM36: Double glazed window, 0.5 inch air space, insulated spacer, low e film (e=0.2), thermally bridged Al-frame – "Heat Mirror 66".	2.05	2	3.17	1	1st score = 3

[1] Final rankings are based on adding the rankings from window sizes 5 and 25 square feet. Lower scores mean better insulation.

Bibliography

B.C. Gas. 1991. Evaluation of External Costs Associated With Natural Gas Use, vol. 1. Vancouver: B.C. Gas.

B.C. Gas. 1992. Least Cost Integrated Resource Plan 1991-2001. Vancouver: B.C. Gas.

B.C. Hydro. 1991. Cost of New Electricity Supply – 1991 Update. Vancouver: B.C. Hydro.

B.C. Hydro. 1993a. Cost of New Electricity Supply 1993. Vancouver: B.C. Hydro.

B.C. Hydro. 1993b. Electricity Conservation Potential Review, 1988-2010: The Residential Sector – Phase I, Unconstrained Potential. Vancouver: B.C. Hydro Power Smart.

B.C. Ministry of Municipal Affairs, Recreation and Housing. 1993. Technical Advisory Committee on Energy Standards in Part 9 of the British Columbia Building Code – draft final report. Victoria: Government Printing Office.

Bonneville Power Administration. 1990. Sensible Living for the 90's: A Portfolio of Case Studies from RCDP Cycle I. Portland, Oregon: Bonneville Power Administration.

Canadian Mortgage and Housing Corporation, Statistical Services Division. 1990. 1989 Canadian Housing Statistics. Ottawa: Beauregard Press.

Department of Finance, Canada. 1993. The Budget 1993. Ottawa: Dept. of Finance. p. 40.

Dubin, Jeffrey A., and Daniel McFadden. 1980. "An Econometric Analysis of Residential Electricity Appliance Holdings and Consumption." mimeo., MIT.

Dumont, R.S., H.W. Orr, and C.P. Hedlin. 1983. "Low-Energy Houses: Measured Energy-Consumption Figures," in ASHRAE Transactions (1983), 264.

Edwin Mansfield. 1988. Microeconomics: Theory/Applications, 6th ed. New York, N.Y.: Norton & Company.

Energy, Mines and Resources Canada (EMR). 1991. HOT2000 User's Manual, version 6. Ottawa: Canadian Home Builders Association.

Frieden, Bernard J., and Kermit Baker. 1983. "The Market Needs Help." Journal of Policy Analysis v. 2, 163-177.

Hartman, Raymond S. 1981. "An Analysis of Department of Energy Residential Appliance Efficiency Standards." The Energy Journal v.2 (July 1981), 49-69.

Hausman, Jerry A., and Paul L. Joskow. 1982. "Evaluating the Costs and Benefits of Appliance Efficiency Standards." American Economic Review v. 72 (May 1982), 220-225.

Hee, Theresa K.Y. 1993. The Potential Role of Financial Lending Criteria on the Demand for Home Energy Conservation. M.B.A. Project, Simon Fraser University.

Bibliography

Murray, Joyce C. Global Warming: Policy analysis and proposal for a Carbon Sink Silviculture Program. M.B.A. Project, Simon Fraser University.

Martin, Brent. 1989. "R-2000 Home Energy Performance Summary," unpublished proceedings from the 1989 Annual Meeting, Solar Energy Society of Canada held in Penticton, B.C.

McLean, Iain. 1987. Public Choice. Massachusetts: Blackwell.

Byers, Richard. 1990. "Environmental benefits of energy efficiency: Impact of Washington State Residential Energy Codes on greenhouse has emissions." Environment v. 4, 7-17.

Sutherland, Ronald J. 1990. "Market Barriers to Energy-Efficiency Investments." The Energy Journal v. 12 n. 3, 15-34.

Washington State Building Code Council. 1991. Washington State Energy Code (1991), 1st ed. Olympia, Washington: Washington State Building Code Council.

Washington State Energy Office. 1989. Cost-Effectiveness of Residential Building Energy Codes – Results of the University of Washington Component Test and the Residential Standards Demonstration Program. Washington State: Government Printing Office.

Weimer, David L., and Aidan R. Vining. 1989. Policy Analysis – Concepts and Practice. Englewood Cliffs, N.J.: Prentice-Hall.