RESEARCH REPORT

Approaching Net Zero Energy in Existing Housing

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Approaching Net Zero Energy in Existing Housing

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List of Acronyms and Abbreviations

ACEEE	American Council for an Energy Efficient Economy
AC/H	Air Change per Hour
ACI	Affordable Comfort Institute (US)
CanSIA	Canadian Solar Industries Association
CSA	Canadian Standards Association
CFL	Compact Fluorescent Lamp
CMHC	Canada Mortgage and Housing Corporation
COP	Coefficient of Performance
DHW	Domestic Hot Water
DWHR	Drainwater Heat Recovery
EBN	Environmental Building News
EDU	Environmental Design Update
EGH	EnerGuide for Houses (Canadian rating service for residential energy use)
EPA	Environmental Protection Agency (US)
GJ	Gigajoule (measurement of energy 1GJ = 0.0036 kWh)
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pump
HRAI	Heating Refrigeration and Air Conditioning Institute
HRV	Heat Recovery Ventilator
HVAC	Heating Ventilation and Air Conditioning
KWp	Peak power in kW of a PV array
LED	Light Emitting Diode
NAHB	National Home Builders Association (US)
NBC	National Building Code (Canada)
NEB	Non-Energy Benefit
NZEH	Net Zero Energy Housing
NRCan	Natural Resources Canada
PV	Photovoltaic
R-value	Thermal resistance value of insulation, in Imperial units
RETScreen	Renewable Energy Technology Software (developed by NRCan)
RSI	Thermal resistance value of insulation, in SI units
SDHW	Solar Domestic Hot Water
SRC	Saskatchewan Research Council
US DoE	United States Department of Energy

Executive Summary

The term Net Zero Energy Housing (NZEH) rose out of the US Department of Energy's Zero Energy Homes research initiative, started in 2000. In 2006, Canada Housing and Mortgage Corporation's (CMHC) EQuilibrium Housing Pilot Demonstration Initiative set the challenge for Canadian homebuilders and developers (CMHC-EQ, 2007). "Net zero energy housing', as defined by CMHC, describes a home that produces as much energy as it consumes annually. This is done through a variety of means, including:

- reducing energy loads through a climate-responsive, high-performance building envelope and use of energy efficient appliances and lights throughout the house
- increased use of passive solar cooling and heating techniques
- high-efficiency mechanical systems that match the lower energy requirements of the home
- space and water heating assisted by commercially available solar thermal systems and heat pumps
- electrical use offset by grid-connected commercially available photovoltaic (PV) systems

Determining cost-effective ways to retrofit houses to meet net zero energy targets is a key element to both energy security and climate change mitigation (CMHC, 2006). To date, most NZEH initiatives have been focussed on new construction. This study looks at ways to approach net zero energy in the over 12 million existing houses in Canada. The age and style of a house as well as variations in regional and historical construction practices and materials choices all require consideration. Approaching net zero energy is more of a challenge in colder regions, yet these are the regions where homeowners can benefit most.

The following table summarizes the benefits and barriers to reaching net zero energy in existing houses.

Table 1e: Benefits/Barriers to Net Zero Energy Retrofits

Benefits	*Barriers*
• Radically reduces or eliminates energy costs • Energy security • National security • Reduced air pollution • Reduce or eliminate green house gas emissions and impact on climate change • Increased thermal comfort • Enhanced indoor air quality and occupant health • Local job generation and use of many domestically produced products and materials	• Initial cost / financing • Knowledge and experience of building industry • Knowledge and experience of building inspectors • Knowledge and experience of financial institutions • Regulations • Minimum setbacks from property lines, etc. • No guarantee of long term solar access • Limitations on wind tower height and use of wind energy systems (WES) • Lack of detailed local wind energy data for WES and passive cooling • Poor utility adoption of power buyback policies • Lack of consumer interest

The goal of the study was to determine ways to approach net zero energy in housing in the Canadian context. Several house types were modelled in HOT2000 for typical energy usage in six cities (Vancouver, Calgary, Toronto, Montreal, Halifax and Whitehorse), and then a series of upgrades was applied to each house type in each city. When all reductions and changes to the base house had been made, a specialized EnerGuide for Houses rating (developed for CMHC's EQuilibrium Housing Initiative) was calculated. This rating (designated as EGH*) takes into account the total net energy consumption, and includes baseload reductions and renewable energy generation.

In general, the modelled upgrades emphasized energy efficiency first, then add-on renewable energy systems. This meant improving the building envelope then upgrading and updating HVAC equipment, appliances and lighting. PV and solar thermal can be installed when economically feasible, or, in cases of houses where the building envelope, HVAC and/or secondary energy use cannot be improved.

As could be expected, there were differences between climatic regions that influenced the challenge of approaching net zero energy in existing houses. The region where retrofits were most likely to come close to net zero energy mainly through building envelope improvements was Vancouver.

The design heat loss indicates how much heat the house will require to maintain a comfortable inside temperature in the most severe winter conditions for a given location. In most cases, where envelope characteristics did not restrict the level of insulation improvements, the design heat loss was reduced by more than half, in some cases by up to three-quarters of the base case house.

The heating load is the amount of energy (in GJ) that the house consumes annually. In general, there were significant reductions in heating loads in all house types, and in all cities, for an average reduction of 81%. The overall range of reductions was from 56% to 96%. House type and age; typical construction patterns; and climatic differences between cities caused the variations in reductions.

The house type that would most easily be retrofitted to net zero energy was the bungalow, where the simple form of the building allows for better results from air sealing and insulation. In addition, the long axis of the house results in a larger, unobstructed or shaded roof face than other house types. This gives the potential for the largest possible roof-mounted PV array and solar domestic hot water system, even if the 4/12 roof typically is not at optimum slope for these technologies in most Canadian regions.

It was shown in the report that retrofits in the $30,000 and $50,000 range was cost effective when refinancing a mortgage. In many cases, the monthly energy savings outweigh the incremental increase in a mortgage payment. This figure is over double the ‘average’ major renovation figure of $12,000 reported in a CMHC study (CMHC, 2006). However, it has been the project team’s experience that homeowners are willing to pay more for what they want, witness the number of $20,000 to $100,000 kitchen renovations.

At this time, an energy retrofit featuring solar DHW and PV cannot compete with the ‘sexiness’ of a major kitchen or luxury bathroom renovation. However, one aspect of whole house energy efficiency retrofits not currently addressed is the value of associated ‘non-energy benefits’ (NEBs). Recent studies show comfort and aesthetic benefits far outweigh energy concerns, and very few homeowners assess the economic benefits of their investments by monitoring energy bills or calculating payback times (Thorne, 2006).

Barriers to actually getting to net zero energy in existing homes include the challenge of coordinating the timing of a retrofit. Making a project cost-effective depends on some planning – for example, if the siding is to be replaced on a home, that is the time to insulate the exterior and upgrade windows. Mechanical equipment is usually replaced under emergency situations, so a change-out to a higher-efficiency, smaller output unit that coordinates with an envelope upgrade requires a clear plan and timely financing. Other barriers are based in the logistics of finding contractors willing and able to do the work required.

The technology and materials are available to reduce energy loads significantly, in existing houses, by a factor of 7 to 9. However, getting to net zero energy in existing houses is completely dependent on the cost of the add-on renewable systems that take the house to net zero energy. Solar thermal systems are market ready with a reasonable payback period, and are a more readily accepted option by homeowners. If there were financial incentives and mechanisms in place, roof-mounted solar thermal systems would become a much more commonplace sight in Canada. PV systems are currently very expensive, with long payback periods for small systems. Until there are reasonable incentives to purchase and operate these systems (tax rebates, purchase incentives, ‘green power’ premiums for grid-connected systems), it will be nearly impossible for homeowner to operate his or her house as a net zero energy home.

Résumé

L’expression Net Zero Energy Housing (NZEH), traduite par « Maison à consommation énergétique nette zéro » (MCENZ), est tirée de l’initiative « Zero Energy Homes » lancée en 2000 par le département de l’Énergie des États-Unis. En 2006, l’initiative de démonstration témoin de la maison EQuilibrium de la Société canadienne d’hypothèques et de logement (SCHL) invitait les constructeurs d’habitations et les promoteurs canadiens à se surpasser (SCHL-EQ, 2007). La « Maison à consommation énergétique nette zéro », tel que l’entend la SCHL, est une maison qui produit autant d’énergie qu’elle en consomme en une année. Pour y parvenir, on a recours à divers moyens, notamment :

- la réduction des charges énergétiques grâce à une enveloppe de bâtiment à haute performance adaptée au climat et à l’utilisation d’électroménagers et d’appareils d’éclairage éconergétiques partout dans la maison;
- une utilisation accrue des techniques solaires passives pour le rafraîchissement et le chauffage des locaux;
- des installations mécaniques à haute efficacité qui vont de pair avec les besoins en énergie réduits de la maison;
- un système de chauffage de l’eau et des locaux assisté d’installations solaires thermiques et de thermopompes déjà vendues dans le commerce;
- une consommation d’électricité compensée par des panneaux photovoltaïques (PV) offerts sur le marché et raccordés au réseau de distribution.

Il est crucial, dans une optique d’approvisionnement en énergie garanti et d’atténuation des effets du changement climatique, de trouver des moyens efficients de rénover des maisons afin qu’elles offrent une consommation énergétique nette zéro (SCHL, 2006). À ce jour, la plupart des initiatives relatives à la MCENZ visaient les nouvelles constructions. Or, cette étude examine des moyens d’envisager la consommation énergétique nette zéro pour plus de 12 millions de maisons existantes au Canada. L’âge et le style d’une maison, en plus de la diversité des pratiques régionales et historiques en matière de construction et de choix des matériaux, sont des facteurs qui doivent tous être pris en considération. Il est vrai qu’il peut s’avérer difficile de parvenir à une consommation énergétique nette zéro dans les régions froides, mais n’oublions pas que ce sont les propriétaires-occupants de ces régions qui peuvent en bénéficier le plus.

Le tableau suivant résume les avantages et les obstacles inhérents à la consommation nette zéro dans les maisons existantes.

Tableau 1e : Rénovations visant une consommation énergétique nette zéro – les avantages et les obstacles

Avantages

- Réduction considérable ou élimination des frais d’énergie
- Approvisionnement en énergie garanti
- Sécurité nationale
- Diminution de la pollution de l’air
- Réduction ou élimination des émissions de gaz à effet de serre et de l’incidence sur le changement climatique
- Confort thermique accru
- Amélioration de la qualité de l’air intérieur et de la santé des occupants
- Création d’emplois à l’échelle régionale et utilisation de nombreux produits et matériaux fabriqués au pays

Obstacles

- Coûts initiaux et financement
- Connaissances et expérience du secteur de la construction
- Connaissances et expérience des inspecteurs en bâtiment
- Connaissances et expérience des institutions financières
- Règlements
- Marges de recul minimales relativement aux limites de la propriété, etc.
- Aucune garantie quant à l’accès à long terme à l’énergie solaire
- Restrictions relatives à la hauteur des tours éoliennes et à l’utilisation de systèmes éoliens
- Absence de données locales détaillées sur l’énergie éolienne pour les systèmes éoliens et le rafraîchissement passif
- Faible taux d’adoption de politiques de rachat d’énergie par les organismes de service public
- Manque d’intérêt de la part des consommateurs

Le but de cette étude était de trouver des moyens de parvenir à des maisons à consommation énergétique nette zéro dans le contexte canadien. Plusieurs types de maisons ont été modélisés à l'aide de HOT2000 pour en connaître la consommation énergétique caractéristique dans six villes (Vancouver, Calgary, Toronto, Montréal, Halifax et Whitehorse), puis une série d'améliorations ont été apportées à chaque type de maison dans chaque ville. Lorsque toutes les réductions et modifications à la maison de référence ont été faites, une cote spéciale ÉnerGuide pour les maisons (élaborée pour l'initiative EQuilibrium de la SCHL) a été calculée. Cette cote (appelée EGM*) tient compte de la consommation d'énergie nette totale et comprend les réductions de la charge minimale requise et la production d'énergie renouvelable.

Règle générale, les améliorations modélisées privilégiaient d'abord l'efficacité énergétique, puis l'ajout de systèmes à énergie renouvelable. On devait donc perfectionner l'enveloppe du bâtiment, puis améliorer et moderniser l'installation de chauffage, ventilation et climatisation (CVC), les électroménagers et les appareils d'éclairage. Des panneaux photovoltaïques et une installation solaire thermique peuvent être mis en place lorsqu'il est économiquement possible de le faire ou dans le cas des maisons où l'enveloppe du bâtiment, l'installation de CVC ou l'utilisation de l'énergie secondaire ne peuvent être améliorés.

Comme on pouvait s'y attendre, on a constaté des différences entre les régions climatiques qui influaient sur la capacité de parvenir à une consommation énergétique nette zéro dans des maisons existantes. C'est dans la région de Vancouver que des rénovations permettraient le plus de se rapprocher d'une consommation énergétique nette zéro grâce aux seules améliorations apportées à l'enveloppe du bâtiment.

Les pertes de chaleur nominales indiquent la quantité de chaleur nécessaire pour que la maison maintienne une température intérieure confortable durant les conditions hivernales les plus rigoureuses dans un endroit donné. Dans la majorité des cas, lorsque les caractéristiques de l'enveloppe n'empêchaient pas l'ajout d'isolant, les pertes de chaleur nominales ont été réduites de plus de la moitié et, dans certains cas, jusqu'aux trois quarts par rapport à la maison de référence.

La charge de chauffage correspond à la quantité d'énergie (en GJ) que la maison consomme en une année. En général, on a constaté des réductions importantes des charges de chauffage dans tous les types de maisons et dans toutes les villes, soit une réduction moyenne de 81 %. La plage globale des réductions s'étendait de 56 % à 96 %. Les écarts dans les réductions étaient causés par le type et l'âge de la maison, les procédés de construction courants et les différences de climat entre les villes.

Le type de maison qui pourrait être le plus facilement rénové pour parvenir à une consommation énergétique nette zéro est la maison de plain-pied, dont la forme simple permet d'obtenir de meilleurs résultats grâce à l'étanchéisation à l'air et à l'isolation. En outre, la forme allongée du bâtiment procure une superficie de toit sans obstruction ni ombrage plus grande que celle des autres types de maisons. On peut donc envisager d'y installer des panneaux photovoltaïques et une installation solaire pour le chauffage de l'eau domestique de dimension optimale, même si une pente de toit de quatre pouces par pied n'est généralement pas la meilleure pour ces technologies dans la plupart des régions du Canada.

Dans le rapport, on démontre que des rénovations se situant entre 30 000 $ et 50 000 $ s'avèrent rentables lors du refinancement d'un prêt hypothécaire. Dans de nombreux cas, les économies d'énergie mensuelles sont plus importantes que l'augmentation des paiements hypothécaires. Ce chiffre représente plus du double des 12 000 $ signalés dans une étude de la SCHL (SCHL, 2006) et constituent une « moyenne » pour de gros travaux de rénovation. Néanmoins, l'équipe de projet sait par expérience que les propriétaires-occupants sont prêts à payer davantage pour ce qu'ils veulent, comme en font foi les sommes de 20 000 $ à 100 000 $ consacrées aux travaux visant les cuisines.

Pour le moment, une rénovation éconergétique faisant appel à un chauffe-eau solaire et à des panneaux photovoltaïques ne peut concurrencer le charme d'une nouvelle cuisine ou d'une salle de bains de luxe. Toutefois, un aspect des rénovations éconergétiques n'a pas encore été abordé : la valeur des avantages non énergétiques connexes. En effet, de récentes études montrent que les avantages relatifs au confort et à l'esthétique dépassent de loin les préoccupations à l'égard de l'énergie, et très peu de propriétaires-occupants évaluent les avantages économiques de leurs investissements en faisant le suivi de leurs factures d'énergie ou en calculant les délais de récupération (Thorne, 2006).

Parmi les obstacles à une consommation énergétique nette zéro dans les maisons existantes, notons la difficulté à coordonner le calendrier des travaux de rénovation. Pour qu'un projet soit rentable, on doit le planifier. Par exemple, si on doit remplacer le bardage d'une maison, c'est le moment tout indiqué pour isoler l'extérieur et améliorer les fenêtres. L'équipement mécanique est habituellement remplacé en situation d'urgence; donc, pour passer à un appareil plus efficace et moins puissant en même temps qu'on améliore l'enveloppe, il faut disposer d'un plan clair et d'un financement opportun. D'autres obstacles viennent de la logistique nécessaire pour trouver des entrepreneurs qui sont prêts à exécuter les travaux requis et en mesure de le faire.

La technologie et les matériaux sont disponibles pour réduire considérablement les charges énergétiques des maisons existantes par un facteur de 7 à 9. Toutefois, en arriver à une consommation énergétique nette zéro dans des maisons existantes dépend entièrement du coût des installations à énergie renouvelable qui permettent d'y parvenir. Les installations thermiques solaires vendues dans le commerce ont un délai de récupération des coûts raisonnable et constituent des options que les propriétaires-occupants acceptent plus facilement. Si on disposait d'incitatifs et de mécanismes financiers, les systèmes thermiques solaires installés sur le toit deviendraient chose courante au Canada. Les systèmes PV sont actuellement très dispendieux, et les délais de récupération sont longs pour les petites installations. Tant qu'il n'y aura pas d'incitatifs raisonnables pour l'achat et l'exploitation de ces systèmes (remboursements de taxes, incitatifs à l'achat, primes « d'énergie verte » pour les systèmes raccordés au réseau de distribution), il sera pratiquement impossible pour les propriétaires-occupants de parvenir à une consommation énergétique nette zéro.

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1 Introduction

1.1 What is Net Zero Energy Housing?

The term Net Zero Energy Housing (NZEH) rose out of the US Department of Energy's Zero Energy Homes research initiative that was begun in 2000, with project teams building demonstration projects through 2002 and 2003 (Charron, 2005). In 2006, Canada Housing and Mortgage Corporation's (CMHC) EQuilibrium Housing Pilot Demonstration Initiative set the challenge of net zero energy for Canadian homebuilders and developers (CMHC-EQ, 2007). 'Net zero energy housing', as defined by CMHC and Natural Resources Canada (NRCan), essentially describes a home that produces as much energy as it consumes on an annual basis. This is accomplished through a variety of means, including:

- reducing energy loads through a climate-responsive, high-performance building envelope and use of energy efficient appliances and lights throughout the house
- increased use of passive solar cooling and heating techniques
- high-efficiency mechanical systems that match the lower energy requirements of the home
- space and water heating assisted by commercially available solar thermal systems and heat pumps
- electrical use offset by grid-connected commercially available photovoltaic (solar electric) systems

To date, most NZEH initiatives have been focussed on new construction (Charron, 2005). This study looks at ways to approach net zero energy in existing houses in Canada. Due to the fact that the majority of housing that will around for the next 50 years already exists, determining cost-effective ways to retrofit houses to meet net zero energy targets is a key element to both energy security and climate change mitigation.

1.2 NZEH and the Existing Housing Stock in Canada

Across the Canada, the existing housing stock was built with little consideration for energy efficiency. There is opportunity to significantly reduce both energy use and greenhouse gas emissions through retrofit projects. Currently, residential uses account for 17% of Canada's national energy requirements and 16 % of overall Canadian GHG emissions (CMHC, 2006).

It is much easier to build a new home to stringent energy specifications than it is to retrofit an existing house, yet new construction accounts for only 2% of the housing stock annually (CMHC, 2006). The bulk of housing that will be standing in 2050 is already built. Houses of various ages and styles pose different challenges to retrofits for energy efficiency. Some older homes have uninsulated, damp basements and structural issues that need to be addressed. These factors affect the approach taken and the cost of making these buildings meet a Net Zero Energy target. Variations in regional and historical construction practices and materials choices need to be taken into consideration. The historic value of buildings, particularly their street façade and the appearance of character-defining elements such as windows and doors have to be accommodated. Climatic differences make approaching net zero energy in existing houses more of a challenge in colder regions, yet these are the regions where homeowners can benefit most.

As could be expected with an US-based initiative such as the Zero Energy Homes research, many of the built examples are in climates that aren't relevant to the Canadian situation. Many houses built under this initiative are in regions with predominantly cooling climates. There are some examples of homes built under this program in the northern states, such as a Habitat for Humanity home in Denver, Colorado, which has been monitored since January 2006 (Norton and Christensen, 2006). In addition, there are several examples of cold-climate homes in North America that approach or attain net zero energy status that are not under the umbrella of this initiative, including some in Canada such as the Toronto Healthy House. European examples in climate regions similar to Canada's are also to be found.

There is a history of practical experience in 'deep' energy retrofitting in Canada. Work done in the late 70's and early 80's includes a 'superinsulated' retrofit on a post war bungalow done by the National Research Council (NRC) small buildings research facility in Saskatoon. In this project, wall insulation levels were raised up to R40 and the roof to R60 and a continuous air and vapour barrier was run around the whole building.[1] These techniques could easily be applied to a net zero energy retrofit today, as improving the

[1] From experience of team member Chris Mattock.

building envelope to reduce energy needs is the number one priority in all literature reviewed. Indeed, one of the twelve EQuilibrium initiative projects, the Now House™ is exploring the net zero retrofit concept. This 60-year-old wartime house, in an established neighbourhood in Toronto, Ontario, represents hundreds of thousands of homes in Canada and is being insulated to levels similar to the Saskatoon house (CMHC-EQ, 2007).

1.3 The Net Zero Energy Retrofit Market Potential

In Canada, existing housing stock represents nearly 12 million units, of which more than thirty-five percent – over 4 million units – are in need of minor to major repairs (CMHC, 2006). Sales of existing houses are holding strong. Many of these units will undergo major renovations in the next several years, as homeowners are renovating existing homes within 3 years of purchase (CMHC, 2006). Renovation spending has more than doubled in the last decade, from $21 billion in 1999 (Think Toronto Homes, 2006) to $49.9 billion in 2007, with projected spending for 2008 of $53.3 billion (Deslongchamps, 2007). In 2007, roughly half of the investment in residential construction was spent on repairs and renovations to existing homes (Conference Board of Canada, 2007). Current major renovation spending per Canadian household hovers around the $12,000 mark. (CMHC, 2007).[2]

The American Council for an Energy Efficient Economy reported that additions, alterations or improvements to interiors accounted for 36% of the total spending on home improvement in the US in 1999 (Thorne, 2003). In the same year, home equipment and HVAC system replacement or upgrades accounted for 44%, and the remaining 20% was spent on other projects, including routine maintenance and repairs as well as outdoor projects and disaster repairs (Thorne, 2003). With these figures in mind, it could be assumed that 40% to 50% of the home improvement dollar is available for retrofits that focus specifically on lowering energy costs. According to analysis of US-based data, annual energy savings from common retrofit measures are as follows (Thorne, 2003)[3]:

20% air sealing (including insulation and window replacements)
15% duct sealing and repair
20% HVAC system upgrade
15% improved HVAC installation practices
10% lighting and appliance upgrades

For Canadian retrofits, the proportions will be somewhat different, as very little of the existing Canadian housing stock would benefit from duct sealing (which is only required when ducting is outside of the conditioned space).

1.4 The Cost of Net Zero Energy Housing Retrofit

A keynote presentation to the Affordable Comfort Institute's Summit on Carbon Neutrality in Summer 2007 estimated that existing housing in the US could see significant reductions in energy (Krigger, 2007, Parker, 2007). Four levels of retrofits were identified, moving from a 'general' energy efficient retrofit to a near zero or net zero energy retrofit as follows:

- Low hanging fruit: costs about US$1500/home, saves 1,000 kWh and 100 therms[4] annually
- Extensive retrofit: costs US$10,000/home, saves 4,000 kWh and 400 therms annually
- Deep retrofit: costs US$50,000/home, saves 7,000 kWh and 600 therms annually
- Deep retrofit + 3kW PV: costs US$75,000/home, saves 7,000 kWh and 600 therms annually and produces an additional 4,300 kWh/yr

According the US-based presenter, the low-level audit listed above would pay for itself in 7 years in most cases. The deep retrofit with PV (near-zero or net zero, depending on occupant lifestyle) would pay for itself in less than 35 years at current costs with a 20% reduction in annual CO_2 emissions for the US. (Parker, 2007). However, there is little likelihood of homeowners taking on deep retrofits with a 3kW PV array at a

[2] In a recent survey by CMHC, approximately 1.5 million households in 10 major Canadian centres surveyed indicated they completed renovations in 2006, costing an average of more than $11,000, with forty-six per cent of homeowners in this survey intending to spend an additional $1,000 this year.

[3] NB: savings are not additive. Total does not equal 100%

[4] 1 therm = 100,000 British Thermal Units (BTUs) = 0.016 gigajoules (GJ)and is approximately 2.75 m^3 natural gas.

cost of $75,000 without support from government agencies (in the form of incentives and tax credits) and lending institutions (in the form of low-interest 'green' mortgages). As fuel prices continue to rise, the option to move towards a net zero energy retrofit will also look better.

1.5 Getting to Net Zero Energy in Existing Buildings

In the report, The Potential Impact of Zero Energy Homes (NAHB, 2006), three scenarios were developed for the adoption of Zero Energy Homes (ZEH) into the new single-family home market and the effect of each scenario on residential energy consumption through 2050. A reference scenario, where household energy use remains relatively constant from today's usage level serves as basis for comparison to a ZEH integration scenario with no incentives and the final scenario: ZEH integration + 30% tax credit. The report states that ZEH are technically feasible today and will eventually become economically competitive with conventional construction as cost trends continue, as solar and energy efficiency technologies improve and when utility costs are included in the cost of home ownership.

Although the study was specific to new construction, one of the key findings of the NAHB study was that for ZEH to succeed in the marketplace, a coordinated effort is needed to conduct research and development in order to reduce the cost of ZEH and to facilitate transformation of the home building and renovation/remodelling market. Activities would likely include outreach to consumers, builders, real estate agents, appraisers and utilities, technical training, policy development and R&D on the integration of ZEH technologies (NAHB, 2006). Although the finding was specific to new homes, the same issues are valid for existing homes, with the same type of activities required to transform the market.

With a net zero energy new home or retrofit project, lending institutions will have to look at ways of revamping their Gross Debt Service (GDS)[5] formulas for mortgages and building loans, as energy costs are no longer a part of the picture. Systems such as EnerGuide for Houses are in place to rate and compare energy efficient retrofits, providing documentation and verification for lenders.

According to a report from the American Council for an Energy Efficient Economy (Thorne, 2003), whole house retrofits are hobbled by the following barriers:

- Up-front cost plays a major role in limiting consumer demand for many efficiency upgrades, even when short payback periods can be demonstrated.
- Limited consumer understanding of the benefits, as efficiency improvements are largely intangible and results of the investment can not be seen, nor shown off to the neighbours.
- Consumers cannot identify the work that needs to be done, nor can they determine which contractors to hire to perform the services the might need
- Timing is everything: equipment replacement is often done in an emergency situation when existing equipment fails.
- Contractors cite lack of consumer demand, but may not have appropriate marketing skills or information to successfully sell improvements or services to their clients.
- Contractors risk investing time and resources in skills upgrades or improvements, as well as in purchasing new equipment. Greater assurance is needed of a persistent market before these investments will be made on a broad scale.
- Contractors may also be reluctant to identify problems beyond their expertise or that cut into their core business (i.e., selling smaller HVAC systems).

Given these barriers and obstacles, the feedback from the builders of the first Net Zero Energy homes built during 2002-2003 under the US Department of Energy's ZEH initiative, brought three interesting points to light (Charron, 2005):

1. The low energy homes appreciated faster than neighbouring homes build to code
2. It was more profitable to include the energy upgrades as standard as opposed to as an option
3. The higher price of the homes with PV systems was not perceptible to the buyers

At the Affordable Comfort Institute's July 2007 summit, "Moving Existing Homes Toward Carbon Neutrality', the main focus was on 'deep energy savings', reductions of 70 to 90 percent in total energy use in existing

[5] The Gross Debt Service ratio is the percentage of gross (or pre-tax) earnings allocated to payment of the mortgage principal and interest, property taxes and energy costs (PITE). This ratio should normally not exceed 32%. Lenders also consider the Total Debt Service (TDS) ratio, the percentage of your gross annual income required to cover fixed payments for all debts and financing obligations, including housing. This ratio must usually not exceed 40%.

single family and multifamily dwellings (Krigger, 2007, Parker, 2007). This summit invited participants to re-examine assumptions about achievable energy reductions through a combination of technical interventions and behavioural choices. Danny Parker, in his keynote address, discussed the 'Chinese restaurant menu' approach, where every meal (or house) is a different combination of choices from a long list of options (Parker 2007).

Unlike the findings of the 2006 NAHB study, which concluded that the technology is ready for early market penetration of NZEH in new construction, but it is not currently economically justifiable to construct NZEH without financial incentives, both keynote speakers at the ACI Summit indicated that deep reductions could be made economically in existing houses (Krigger, 2007, Parker, 2007). High-priced add-ons such as PV systems are seen as a final option for most homeowners. However, with a decent incentive program in place and under conservative assumptions of output and equipment life, a 2 kW PV system could represent an annual return on investment (ROI) of roughly 9% (Black, 2004).

Krigger points out that the expectations for comfort levels in a home are (and will be) a large driver of success or failure to approaching net zero energy in existing houses. North Americans have become acclimated to central heating in homes, with reasonably even heat distribution. Typical temperature swings in North American homes range from 18 to 22* C (68 to 74° F). In a Passivhaus, acceptable seasonal interior temperature swings vary dramatically from North American standards, with lows of 13 to 16* C (55 to 60° F) being acceptable, and an additional sweater being an appropriate solution to being chilly. In Japan, an annual daily temperature range of 16 to 32* C (60 to 90° F) is acceptable. With a wider variation in temperature being the 'norm', it becomes easier to meet lower energy targets and to accommodate higher levels of passive solar gain without more energy-using controls and shading devices (Krigger, 2007).[6]

"Let no one tell us that insulation, shading, air sealing, and other conservation measures are too expensive. Too expensive compared to what? Compared to what we spend on fireplaces, spas, and unnecessary light fixtures for our homes? Compared to the cost of securing our supplies of middle-east oil? C'mon we already spend $40 billion on building renovation every year. Adding another 20 percent to our major renovation budget is probably all we need to start securing deep reductions." (Krigger, 2007)

The table below summarizes the primary benefits and barriers to reaching net zero energy targets in existing houses.

Table 1: Benefits/Barriers to Net Zero Energy Retrofits

Benefits

- Radically reduces or eliminates energy costs
- Energy security
- National security
- Reduced air pollution
- Reduce or eliminate green house gas emissions and impact on climate change
- Increased thermal comfort
- Enhanced indoor air quality and occupant health
- Local job generation and use of many domestically produced products and materials
- Reduces or eliminates peak electrical demand

Barriers

- Initial cost / financing
- Knowledge and experience of building industry
- Knowledge and experience of building inspectors
- Knowledge and experience of financial institutions
- Regulations
- Minimum setbacks from property lines and adjacent buildings
- No guarantee of long term solar access
- Limitations on wind tower height and use of wind energy systems (WES)
- Lack of detailed local wind energy data for WES and passive cooling
- Poor utility adoption of power buyback policies
- Lack of consumer interest

[6] According to Anil Parekh, Senior Researcher, Buildings Group, CANMET Energy Centre, there is an implication of interstitial condensation in cold climates with lower setpoint temperatures. Even in well insulated/constructed houses, interior temperatures below 16° or 17°C can cause problems.

2 Goals of the Project

The goal of the study was to determine ways to approach net zero energy in housing in the Canadian context, where homes are located in predominantly heating climates. Several house types were modelled for typical energy usage in six cities, and then a series of upgrades was applied to each house type in each city. Questions explored in the study include:

- Which, if any, house types are better suited to net zero energy retrofits?
- Which, if any, locations are better suited to net zero energy retrofits?
- Where houses cannot be modified to increase insulation levels, are there options that can lead to a net zero energy home?
- How does each step impact the energy load of a house?
- What techniques can be used to enhance building envelope performance to meet the goal of net zero energy?
- What techniques can be used to enhance passive solar utilization?
- What modifications to mechanical systems are required in a net zero retrofit?
- How would the slopes of existing roofs affect the performance of solar thermal and PV systems?
- What areas of solar thermal collectors and PV arrays would be required?

2.1 Methodology Used to Model Net Zero Energy Retrofits

A number of house types were identified as being common in the Canadian housing stock. They were determined in part through Canada Mortgage and Housing Corporation’s Renovating for Energy Savings Series (CMHC, 2004). This series of brochures discusses energy efficiency measures specific to eleven house types, as well as measures that are common to most existing housing. The house types include three versions of a pre World War II 2-1/2 storey house, one with removable siding, one with a brick veneer and one with a double wythe brick wall. These three subtypes offer a range of challenges in approaching net zero energy. Two common house types, a 2 storey home and a bungalow/rancher, both with full basements, were modelled in two ways. The first model was carried out using the median age for the house type, while the second model was carried out using the year 2000. This meant the house would have been built under the National Building Code (NBC) 1995, which included a requirement for mechanical ventilation, among other current residential construction practices. Upgrading from a house built under this code would have different challenges than the older version, as insulation levels in general would be higher, air leakage rates would be lower and mechanical systems would be newer and possibly more efficient.

The house types used in this study are outlined in the table below. They were modelled in Vancouver, Calgary, Toronto, Montreal, Halifax and Whitehorse using HOT2000™ v.10.10, in the EnerGuide for Houses mode. The base house characteristics were developed from the EnerGuide for Houses archetype database, provided by Natural Resources Canada and previous work carried out for the Renovating for Energy Savings Series (CMHC, 2004). This data determined the thermal envelope and mechanical systems typical for the house type, age and location.

Table 2: House Types

House Type	Ave. Date of Construction	Ave. Volume (m^3)	Average Floor Area (m^2)	Average Bsmt Area (m^2)	Notes:
Pre WW II - A	1922	451	183	68	2x4 stick frame w/removable siding Roof slope = 9/12
Pre WW II - B	1922	451	183	68	2x4 stick frame w/brick veneer Roof slope = 9/12
Pre WW II - C	1922	451	183	68	2x4 double or triple wythe brick Roof slope = 9/12
Post War 1-1/2 storey	1952	471	197	70	2x4 stick frame w/removable siding Roof slope = 12/12
2 storey	1988	705	285	84	2x4 stick frame w/removable siding Post 1960 Roof slope = 4/12
	2000	770	309	103	2x6 stick frame w/removable siding NBC 1995 (from EGH Archetypes) Roof slope = 4/12
Bungalow/Rancher	1969	481	204	98	2x4 stick frame w/removable siding 1960-1979 Roof slope = 4/12
	2000	515	206	103	2x6 stick frame w/removable siding NBC 1995 (from EGH Archetypes) Roof slope = 4/12
Split Level	1985	501	203	71	2x4 stick frame w/removable siding Roof slope = 4/12
Split Entry	1980	526	210	89	2x4 stick frame w/removable siding Roof slope = 4/12
Duplex (Up and Down)	1965	563	227	57	2x4 stick frame w/removable siding Roof slope = 6/12 Montreal: flat roof
Row House	1965	563	227	57	2x4 stick frame w/removable siding Roof slope = 8/12

Notes for this table:
The Pre WWII house was modelled with removable siding in all cities (A), with brick veneer in Toronto, Montreal and Halifax only (B), and as a double wythe brick wall in Toronto and Montreal only (C).
The row house was not modelled in Whitehorse.

The base case house was then upgraded through the energy modelling software. All characteristics of base and upgrade cases are noted in detail in the next sections. Following is a summary of the process used to upgrade the houses. Net zero energy was determined using the protocols developed for CMHC's EQuilibrium Housing Initiative.

The first action was to improve building envelopes where possible, to a target determined through comparing EQuilibrium Housing project envelopes, work by Canadian builders, project team members' design and consulting experience, as well as European standards for low-energy homes. Upgrades to the building enveloped were followed by upgrades to mechanical systems (including increased mechanical ventilation for older homes with tighter envelopes). Where building envelopes could not be improved, other options for energy reduction were explored, such as ground source heat pumps (GSHP). Solar hot water systems were included for all houses, based on 6 m^2 of flat plate solar collector along with 240L of storage. The use of evacuated tube collectors were also investigated but despite higher efficiencies proved to be more costly for delivered MJ than the flat plate collector systems. The system configuration and solar contributions to water heating were determined as outlined below.

These steps produced an upgrade case with a higher EnerGuide for Houses (EGH) rating. This first upgrade rating had to be 82 or more on the EGH scale, using standard mechanical equipment and with no renewable energy.

To further reduce water heating energy use, a drainwater heat recovery unit was added to the model, with an estimated 20% reduction to overall water heating needs.

Photovoltaics were included as the final step. An annual base electrical load of 31.5 GJ (8670 kWh) was required by the EQuilibrium Housing Initiative specifications. This was used as the stepping-off point for the PV system requirements. The resulting area required for the array was larger than the potentially available roof face area on most of the house types, so the system was downsized to fit the roof, with an average kWh/m^2 figure determined from the initial analysis. This downsized PV array also had a lower annual electrical contribution, so the annual electrical base load was dropped to 13.1 GJ (3638 kWh) by improving the efficiency of appliances, lighting and other loads.

When all reductions and changes to the base house had been made, a specialized EnerGuide for Houses rating was calculated. This specialized rating (designated as EGH*) takes into consideration the total net energy consumption. In the EQuilibrium Housing Initiative, designs that did not reach and EGH* rating of 90 or more were not eligible to be included. The non-linear nature of the EGH* scoring scale reflects the fact that improving the EGH* rating becomes more difficult the closer to 100. The modified EGH rating allows for reductions in base load electricity and hot water use. See Appendix G for the detailed equations for the EGH* rating

The EGH* rating is defined as

$$\text{EGH* rating} = 100 - \frac{(\text{Annual Estimated Energy Consumption}) * 20}{\text{Reference Energy Consumption}}$$

The reference Energy Consumption = space heating benchmark + DHW benchmark + baseload benchmark + air conditioning energy

3 Characterization of Existing Housing Stock in Canada

The table below shows the house types and the cities in which they were modelled. Not all cities have a significant number of every house type. The following table shows the general envelope characteristics of each house type, regardless of city. Average insulation levels for each house type vary with the city they are built in, with Calgary and Whitehorse having higher average levels than the other four cities. The third table shows general mechanical system characteristics for all house types. These characteristics were determined using the EnerGuide for Houses archetypes from Natural Resources Canada, Buildings Group.

All of the houses were modelled with the front of the house facing North. Typically, this puts a large proportion of the glazing out of passive solar gain, giving a 'worst case' scenario for the space heating requirements for the house.

Table 3: Characteristics of House Types

House Type	Ave. Date of Const.	Ave. Volume (m^3)	Ave. Floor Area (m^2)	Ave. Bsmt Area (m^2)	construction type and/or period	VANCOUVER	CALGARY	TORONTO	MONTEAL	HALIFAX	WHITEHORSE
Pre WW II 2-1/2 storey	1922	451	183	68	stick frame w/ removable siding Roof slope = 9/12	X	X	X	X	X	X
					stick frame w/brick veneer Roof slope = 9/12			X	X	X	
					double or triple wythe brick Roof slope = 9/12			X	X		
Post War 1-1/2 storey	1952	471	197	70	Roof slope = 12/12	X	X	X	X	X	X
2 storey	1988	705	285	84	Post 1960 Roof slope = 4/12	X	X	X	X	X	X
	2000	770	309	103	Meets NBC 1995 Roof slope = 4/12	X	X	X	X	X	X
Bungalow	1969	481	204	98	1960-1979 Roof slope = 4/12	X	X	X	X	X	X
	2000	515	206	103	Meets NBC 1995 Roof slope = 4/12	X	X	X	X	X	X
Split Level	1985	501	203	71	Roof slope = 4/12	X	X	X	X	X	X
Split Entry	1980	526	210	89	Roof slope = 4/12	X	X	X	X	X	X
Duplex (Up and Down)	1965	563	227	57	Roof slope = 6/12 Montreal: flat roof			X	X		
Row House	1965	563	227	57	Roof slope = 8/12	X	X	X	X	X	

3.1 Typical Existing Envelope Characteristics

The existing envelope characteristics on the following page were taken from the database of housing archetypes provided by NRCan. The AC/H@50 column indicates the number of times the volume of air in the house is exchanged per hour, under standardized test conditions. The insulation levels are shown in RSIunits. The database did not include U-values for windows. These were modelled from within HOT2000™ by inputting the window type, based on the Table 3 inputs.

Table 4: Existing Envelope Characteristics, for All House Types

	AC/H@50						Roof/Ceiling (RSI)						Above Grade Walls (RSI)						Below Grade Walls (RSI)							Exposed Floors (RSI)				
House Type	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
Pre WW II	12.3	8.4	10.8	8.0	10.9	11.7	2.8	4	3	3.4	2.2	3.9	1.3	1.5	1.2	1.8	1.6	2.1	0.9	1	0.5	1.1	0.4	0.5	1.6	2.8	2.2	2.8	1.8	
Post War 1-1/2 storey	11.4	6	7.9	5.6	7.8	6.8	3.3	4.6	3.7	3.9	3.0	4.7	1.5	1.8	1. 4	1.9	1.9	2.2	0.9	1.2	0.7	1.2	0.6	1.4	1.2	3.1	2.8	2.2	2.1	4.2
2 storey	6.9	4	4.3	3.5	5.5	4.5	4.8	5.5	5.2	5.6	4.8	6.0	2	2.6	2.4	3	2.6	3.0	1	2.3	1.6	1.9	1.4	2.6	1.4	4.5	4.2	4.6	3.9	4.2
New 2 storey	5.2	3.4	3.3	3.1	3.5	4.7	5.9	6.5	5.4	5.7	6.4	6.3	2.2	2.7	2.8	3.1	3.0	3	1.5	2.4	1.9	2.2	1.8	2.0	1.4	4.8	5.0	4.7	4.2	4.6
Bungalow/Rancher	9.9	4.2	6.1	3.9	6.4	5.4	3.5	4.5	4.3	4.0	3.5	4.9	1.7	1.9	1.8	2.1	2.0	2.4	1	1.3	0.8	1.4	0.9	1.8	1.6	3.6	3	2.7	2.4	3.8
New bungalow	5.2	3.4	3.3	3.1	3.5	4.7	5.9	6.5	5.4	5.7	6.4	6.3	2.2	2.7	2.8	3.1	3.0	3	1.5	2.4	1.9	2.2	1.8	2.0	1.4	4.8	5.0	4.7	4.2	4.6
Split Level	6.9	4	4.3	3.5	5.5	4.5	4.8	5.5	5.2	5.6	4.8	6.0	2	2.6	2.4	2.9	2.6	3.0	1	2.3	1.6	1.9	1.4	2.6	1.4	4.5	4.2	4.6	3.9	4.2
Split Entry	9.4	4.8	5.1	3.9	6.1	5.3	4	4.6	4.8	4.6	4	5.7	1.9	2.0	2.1	2.6	2.4	2.8	1	1.6	1.4	1.8	1.3	2.5	1.6	3.9	3.5	3.6	3.4	4.6
Duplex (Up/Down)	9.9	4.2	6.1	3.9	6.4	5.4	3.5	4.5	4.3	4.0	3.5	4.9	1.7	1.9	1.8	2.1	2.0	2.4	1	1.3	0.8	1.4	0.9	1.8	1.6	3.1	3	2.7	2.4	3.8
Row House	9.9	4.2	6.1	3.9	6.4	5.4	3.5	4.5	4.3	4.0	3.5	4.9	1.7	1.9	1.8	2.1	2.0	2.4	0.98	1.3	0.8	1.4	0.9	1.8	1.6	3.1	3	2.7	2.4	3.8

Note for this table: RSI is (m^2K)/W, all whole numbers indicate rounded figures.

3.2 Typical Existing Mechanical Systems

Assumptions:

- Space Heating - HOT2000 ™ defaults were used to model the performance of the system
  Medium temperature rise allowed (2.8°C)
- Water Heating - HOT2000 ™ defaults were used to model the performance of the system
  Water T = 55°C
  No tank insulation added to the electric water heaters, no pipe insulation added to the gas/oil fired systems.
- Ventilation - Whole house ventilation is not provided in any house types except for houses built under NBC 1995, which requires ventilation system to be designed around CSA F-326. Assumed these houses have a low-efficiency HRV installed (default performance values in HOT2000 ™ energy modelling software). Not all homes will have HRVs installed. Other mechanical ventilation systems installed in new homes include supply air ducted into the return air plenum of the furnace, controlled by a central dehumidistat-operated fan.

Table 5: Base Case Mechanical Systems, for All House Types

	Space Heating	Water Heating
Vancouver	Mid-efficiency gas fired furnace (78% steady state efficiency)	Gas-fired conventional tank w/continuous pilot (Energy factor = 0.55)
Calgary	Mid-efficiency gas fired furnace (78% steady state efficiency)	Gas-fired conventional tank w/continuous pilot (Energy factor = 0.55)
Toronto	Mid-efficiency gas fired furnace (78% steady state efficiency)	Gas-fired conventional tank w/continuous pilot (Energy factor = 0.55)
Montreal	Electric furnace (100)	Conventional electric water tank (Energy factor = 0.82)
Halifax	Mid-efficiency oil-fired furnace (71% steady state efficiency)	Conventional electric water tank (Energy factor = 0.82)
Whitehorse	Mid-efficiency oil-fired furnace (71% steady state efficiency)	Conventional oil-fired water tank (Energy factor = 0.53)

3.3 Typical Existing Base Loads

Typical base loads include all major appliances, lighting and electronics

Table 6: Existing Base Loads, for All House Types

	kWh/day	kWh/yr
Appliances	14	5110
Lighting	3	1095
Other (electronics etc)	3	1095
Exterior Loads	4	1460
Total base load (kWh)	24	8760
Total annual base load (GJ) (converted from kWh)		31.5

4 Strategies for Approaching Net Zero Energy

The following strategies build on each other to improve the overall performance of a house. The first strategy – performance-based construction standards -- creates a set of energy-related targets that can be met in various ways, giving homeowners, builders and designers a broad menu of options to choose from.

4.1 Performance-based Construction Standards

There are several existing standards for new construction that can bring houses to a near zero or net zero energy state. Of special interest is the Passivhaus standard, as it is a performance-based, as opposed to a prescriptive standard, developed for cold-climate housing. This standard is being used in Germany, the UK and Ireland. 'Minergie-P' is the name of a similar Swiss standard[7]. Existing housing is more challenging than new housing in terms of energy efficiency measures because of the variables between house types, and even between two houses of the same type, not to mention the variations in lifestyle and energy use patterns of the occupants (Parker, 2007). Performance-based models for NZEH would be more viable than a prescriptive standard or code for existing homes, and, for that matter, new construction.

The Passivhaus Standard was developed in Germany in 1996 by an independent private research institution with a focus on research and development of highly energy efficient buildings and systems. From 1997 to 2002, the European Commission funded the development of the Passive House Energy Standard as a leading standard for energy efficient design and construction (Feist, 2005, Saïd, 2006, 66-67, Krigger, 2007). The Passivhaus program, with over 5,000 houses built prior to 2005, has created an industry niche in Austria and Germany, developing and producing components such as low capacity compact HVAC units, windows and doors and innovative building systems (Krigger, 2007).

Passivhaus standards for new construction are as follows: no more than 10 Watts of heating capacity per meter squared of conditioned space, with no more than 15 kWh of heating energy used per meter squared annually, and a total on-site consumption of less than 120 kWh per meter squared annually. This heating load is so low that 30 cfm per person of ventilation air can distribute the heat throughout the house. (Feist, 2005, Krigger, 2007). Whether these buildings perform as well as they are modelled is yet to be seen. Below is a table outlining a Passivhaus energy load for a 100 m^2 house in a Central European climate.

Table 7: Passivhaus Standard for Central European Climate (from Saïd, 2006, 67)*

Requirement	Per unit requirement	100 m^2 house
Maximum annual heating requirement	15 kWh/m^2 (4,755 Btu/s.f)	1,500 kWh (5.4 GJ)
Maximum combined annual energy use	120 kWh/m^2 (38,000 Btu/s.f)	12,000 kWh (43.2 GJ)
Maximum heating load	10 W/m^2 (3.2 Btu/s.f)	1,000W (3414Btu)
Minimum R-value for walls and doors	RSI 6.7 (R 38)	
Air tightness Standard	Maximum 0.6 AC/H @ 50 Pa	
Minimum window R-value	RSI 1.2 (R 7)	
Typical glazing	Triple pane, gas-filled with 2 low-e coatings	
Minimum HRV efficiency	80%	
Blower Door Testing	Required for every house	

* Based on 4000 heating degree days (HDD) at base 18°C, accessed at ec.europa.eu/energy/res/publications/doc2/EN/HANNO_EN.PDF

[7] retrieved December 10, 2007 from en.wikipedia.org/wiki/Passive_house

4.2 Building Envelope

Approaching net zero energy in both new and existing housing puts emphasis on energy efficiency first, then add-on renewable energy systems. Improving the building envelope remains the most cost-effective way of reducing overall energy loads, followed closely by upgrading and updating HVAC equipment, appliances and lighting (Forsthoefel, 2001, Henderson, 2004, Parker, 2007, Pettit, 2007a, Thorne, 2003, USDOE, 2004, USHUD1, 2002, USHUD2, 2003, Saïd, 2006, Wilson and Wendt, 2007). PV and solar thermal are add-ons that can be installed when economically feasible, or, in cases of houses where the building envelope, HVAC and/or secondary energy use cannot be improved. For homes with inefficient building envelopes that cannot be improved, such as older homes with heritage construction techniques and features such as double or triple wythe brick envelopes, one option to approach net zero energy would be a ground source heat pump.

Air sealing is the first line of defense in cold-climate energy reduction. Industry stakeholder recommendations indicate that products and/or best practice installation techniques that better address the need to maintain a tight envelope are needed. For example, the energy savings potential for improving air leakage performance on recessed lighting is high: one conventional recessed fixture can be responsible for an annual loss of between $5 and $30 worth of energy. Ten or more fixtures represent over 10% of the total air leakage through the envelope (as measured by a blower door test). Sealing these units, or installing well-sealed units, can account for 5 to 10% of heating and cooling loads (Plympton et al, 2007). The July 2007 issue of Environmental Building News includes a priority checklist for low-energy retrofits. The following is derived from that checklist, focussing on cold climate priorities.

Table 8: Energy Efficiency Retrofit Priorities Checklist

Building Envelope	Mechanical Systems	House Interior
Air seal foundations and attic	Tune HVAC systems	Replace incandescent lights
Fix moisture problems and insulate basement walls	Insulate water heater	Upgrade appliances
Air seal around the house	Reduce hot water demand	Turn off the TV & computer
Add insulation to attic	Install set-back thermostats	Turn off cable modems and routers
When replacing siding or roofing, insulate walls and roof at exterior w/rigid foam	Replace furnace or boiler	Practice a low-energy lifestyle
Upgrade windows	Install mechanical ventilation	

The literature review of Building Envelope, Heating and Ventilating Practices and Technologies for Extreme Climates (Saïd, 2006) is part of a four-year project to develop durable, energy efficient building envelope assemblies to meet the challenges of environmental conditions in Northern Canada as well as northern coastal regions. Of value to this project are the discussions of temperature and moisture effects on Canadian houses generally and northern houses in particular. As well, the summaries of five super-insulated houses, including their energy budgets are significant (see table below). Although the case studies are all new construction, several types of wall assemblies are discussed, including double stud, stand off, rigid core panel and structural insulated pane systems, all of which can be options for improving the thermal envelope of existing houses.

In addition to the examples in the Saïd paper, there are several Canadian projects of note, houses that approach net zero through energy efficiency first. The Factor 9 Home in Regina, instigated by Communities of Tomorrow and carried out by the Saskatchewan Research Council (SRC) with the participation of the homeowners, is a demonstration project completed in early 2007. This house aims to reduce greenhouse gas emissions by up to 90% of that of a typical Regina home through energy efficiency and environmental performance measures (Henderson, 2007).

The Factor 9 energy target for this house resulted from multiplying several factors dealing with energy consumption, greenhouse gas emissions and material consumption per capita. The home is projected to use 9 times less energy per square meter of floor area than the average existing home in Saskatchewan, for an average annual purchased energy rate of 27.5 kWh/m^2. This figure is well below the Passivhaus standard of combined annual energy use of 120 kWh/m^2. To achieve these goals, the house features a super-insulated envelope, a combination solar thermal space and water heating system and drainwater heat recovery. The house is also PV ready. A wood-burning appliance provides supplementary heat.

Table 9: Factor 9 Home Energy Statistics

Annual purchased energy	27.5 kWh/m^2
Annual Space and Water Heating	17.5 kWh/m^2
Annual lighting and appliances	10 kWh/m^2

It should be noted that a wood energy source makes it impossible to gauge the actual energy produced. Moisture content of individual pieces of firewood, a range of potential heat energy from the different species, the competence of the firebuilder and the efficiency of the wood-burning appliance under various conditions are just a few of the variables included in determining the energy produced by wood. As a result, efforts to properly track energy use and attain net zero energy use in a house are skewed by including a wood energy source. It is not known if the table above includes wood energy in the annual space and water heating statistics.

Table 10: Characteristics of Five Super-Insulated Homes (from Saïd, 2006, 72)

Characteristic	Eagle Lake House (CMHC, 2003)	Saskatoon House (Dumont, 2000)	Alberta Sust. Home (Rieger & Byrne, 1996)	Hanover House (EBN, 1998)	Klingenberg House (EDU, 2004-2)
Wall Framing	wood I joist	400 mm (16") Double 2x4 walls	325 mm (12") Double 2x4 walls	290 mm (11.5") Double 2x4 walls	300 mm (12") wood I joist
Wall	RSI 8.8 (R 50) c/w double drywall (heat sink)	RSI 10.6 (R 60) blown-in cellulose	RSI 8.8 (R 50) blown-in cellulose	RSI 7 (R 40) blown dense-pack cellulose	10.6 (60) 300 mm (12") blown f/g with 100 mm (4") rigid polystyrene
Roof	RSI 10.6 (R 60) blown-in fiberglass	RSI 14.1 (R 80) blown-in cellulose	RSI 13 (R 74) blown in cellulose	RSI 10.6 (R 60) blown-in cellulose	10.6 (60) blown-in flibreglass
Floor	RSI 5.3 (R 30) three layers of styrofoam	RSI 6.2 (R 35)	Rigid foam under slab c/w horiz. skirt (no values listed)	N/a	10.0 (56) expanded polystyrene foam under slab
Basement Walls	N/A	10.6 (60) blown-in cellulose	N/A	RSI 1.9 (R 11) f/g@ inside Headers = 7 (40)	4.2 (24) expanded polystyrene @ outside
Windows	Triple glazed, low-e casement provide cross-ventilation for summer	RSI 0.9 (R 5) triple glazed, two low-e coatings, argon gas fill, low conductivity spacers,	RSI 3 (R 17) five glazings (two glass, three heat mirror film) Krypton fill, insulating spacers	RSI 1.2 and 1.6 (R 6.7 and 9), insulated f/g frames, 3/4 of glazing on S side	1.26 (7.14) triple glazed, argon fill, low-e coating
Air Tightness (AC/H@50 Pa)	Not listed	0.47	Not listed	0.37	Not measured
Power and heating strategies	Uses a 90% efficient EcoNomad® (c/w 6 kW diesel generator) combined heating and utilities unit for heat, electricity, drinkable water and wastewater management for a family of 5. Electricity backup PV = 300 W Wind= 500 W	High passive solar gain. 15.6 m^2 (168 s.f) active solar hot water system w/5300 L (1400 gal) water storage tank for space and water heating via water-to-air heat exchanger in forced air furnace. Additional heat by 5 electric baseboards.	High passive solar gain. GSHP. Wood-fired masonry unit for b/up space and water heating as well as cooking and baking. A 360 L(80 US gallon) hot water tank has heat exchange coils for the fireplace, solar thermal system and in-floor radiant heat	High passive solar gain. Drain-back solar thermal (33 m^2 (360 s.f.) collector and 4500 L (1200 gal) storage) w/52 gal electric water tank for b/up space and water heating. A water-to-air heat exchanger supplies forced air delivery.	A 1000W electric resistance element in the HRV supplies space heating to the house. An instantaneous electric water heater provides DHW.
Energy Use	About 40% reduction in overall energy savings	46.9 kWh/m^2 vs. 200 kWh/m^2 for conventionally built home in Saskatchewan		Total average electric consumption = 29 kWh/m^2 (2.7 kWh/s.f.) Space and water heating Supplemental = 10.7 kWh/m^2 (0.99 kWh/s.f.)	House does not typically need heat: Jan/04 (two cloudy weeks and temps as low as –23°C) total electrical consumption for all household uses (including heating) was 240 kWh.

Note to this table: All insulation values are shown as RSI (R), where RSI is (m^2K)/W and R is h•ft^{2}F/Btu

4.3 Mechanical Systems

Typically, mechanical equipment is replaced when it fails. This is quite often an emergency situation, where no time is available for deliberation and research on the part of homeowners. The energy savings possible due to correct operation, installation and sizing of the HVAC system are typically among the largest of the energy efficiency measures that can be taken in the home. In the US, such measures as sealing ducts that run through unconditioned spaces can lead to 20% reduction in heating energy consumption alone for homes with forced air systems (LBL 2005). Duct sealing is not such a priority for Canadian houses, where typical practice is to run ductwork through conditioned spaces. Other significant measures that can be taken with HVAC systems include downsizing heating and cooling plants to match loads, insulating any exposed ductwork and installing programmable thermostats. The "Best Practices Guide for residential HVAC Retrofits" (Walker, 2003) recognizes the reality that most HVAC replacement occurs in emergency situations and provides the tools (Including a screening tool) for a contractor to make quick informed decisions that enhance the thermal and energy performance of HVAC systems.

Air handlers are often a major source of air leakage in a forced air distribution system. As air handlers can be located in unconditioned or dusty, damp or unused spaces such as garages, attics, crawlspaces and basements, they can also pose a health risk and contribute to moisture damage. Industry stakeholders point to improvements in furnace and air-handling cabinets to result in near zero air leakage, along with opportunities to improve energy performance of heating and cooling systems through improved fan blade design, more efficient motors and the design of the housing around the fan (Plympton et al, 2007). They also point to smart HVAC controls with on-board fault detection systems to save energy caused by HVAC faults and improper operation, and note that additional potential benefits include increased life of the HVAC system and reduced maintenance costs. With these types of installations attention must also be paid to air sealing penetrations of the air barrier.

Stand-alone and whole-building dehumidifiers are other areas where industry stakeholders have noted the potential for significant energy savings: dehumidifiers typically consume as much electricity as an average refrigerator. In addition, dehumidifiers generate heat when they are running, typically during the cooling season. The simultaneous use of dehumidifiers and air conditioners results in one system fighting the other to maintain acceptable interior comfort. Preliminary energy savings estimates suggest that integrated systems can save 20% (650 kWh/yr) of typical cooling and dehumidification energy usage (Plympton et al, 2007).

Table 11: HVAC Replacement Screening Checklist
(Adapted for Canadian housing from Walker, 2003)

Measurement/ Observation	Potential Target value	Potential Retrofit Action
Duct insulation	RSI 1 (R6) to(RSI 1.4R8)	Add insulation to all ducts outside conditioned space
Air flows at registers	Compare to ACCA manual J or HRAI standard	Replace registers, open/close dampers, reduce system flow resistance by straightening existing ducts or replacing them with straight runs.
Air handler flow	Cooling: >400 >350 cfm/ton Heating: 12.5 cfm/kBtu/h	Replace filters, fix duct restrictions, change fan speed, replace fan with high efficient unit, add extra returns in restricted systems
Filter Condition	Clean and at least MERV 6[8]	Replace with MERV 6 or better. Use 50 or 100 mm (2 or 4 inch) filters.
Thermostat Setting also include night setback	Heating: 20°C (68°F) Cooling: 25°C (78°F)	Thermostat raised in summer and lowered in winter to account for better distribution, mixing and envelope improvements. Replace older units w/electronic, programmable thermostats
Spot Ventilation	24L/s (50 cfm) bath, 47 L/s (100 cfm) kitchen	Replace fans, fix restrictive ducting
Spot Ventilation Power	1.2 L/s/W (2.5 cfm/W). (See HVI directory)	Replace with higher efficiency unit, remove/reduce duct flow restrictions, clean fan and ducting
Equipment capacity/efficiency	CSA-F280[9] or CMHC's furnace billing sizing method[10], or ASHRAE Manual S[11]	Replace heating and/or cooling equipment with correct size, eliminate chimney w/direct vent unit, integrate space and water heating equipment, use high efficiency fans
Refrigerant charge	Use superheat or subcooling tests	Add/subtract cooling system refrigerant
Age and Condition of HVAC system	Clean and undamaged.	Clean the system, repair damage or replace if +15 years old, eliminate chimney w/high efficiency direct vent unit, integrate space and water heating equipment
Location of equipment and ducts	Inside conditioned space	Seal and insulate duct locations to make them more like conditioned space, or move system location.
Window A/C units	EnergyStar compliant	Replace with central unit or improved distribution
Multiple systems/zoning	System and controls in good working order	Ensure correct damper operation, check capacity system/zone matches a CSA F-280 (or ASHRAE Manual J) load calculation
Envelope leakage	Normalized Leakage Area = 0.35	Insulate envelope, seal windows/doors/other openings
Moisture testing	No moisture problems	Source control – better kitchen and bath venting, fix flashing/detailing, seal crawlspaces, replace windows, add insulation
House insulation	Insulation levels vary with region	Add insulation as required. Floor or slab depends on local codes.
Windows	Double-or tripled-glazed, low-e, units with insulating spacers	Replace windows.
Window shading	South and/or west facing windows	Add exterior shading to reduce solar loads
Evaluate energy bills	(if available)	
Occupant survey/ Energy Audit	No problems	Moisture removal strategies, new windows, improve air mixing/remove drafts, add envelope insulation, etc.

4.4 Cooling Strategies

An increasing number of homes in Canada have mechanical cooling systems installed, increasing the capital cost of the home and its operating costs as well as greenhouse gas emissions associated with more energy use. Cooling loads can be significantly reduced without adding mechanical cooling. In some cases, particularly in coastal and mountainous regions, the need for mechanical cooling can be eliminated altogether. However southern Manitoba, Ontario and Quebec experience hot humid summers that require mechanical cooling for comfort and dehumidification. In those climates, cooling loads should be minimized, and the most efficient, properly sized ENERGY STAR® rated mechanical cooling equipment should be used.

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[8] MERV is an industry standard rating system for air filters, it stands for Minimum Efficiency Report Value determined using ASHRAE Standard 52.2

[9] CSA Standard F-280 "Determining the Required Capacity of Residential Space Heating and Cooling Systems"

[10] details on this method can be found at www.cmhc-schl.gc.ca/publications/en/rh-pr/tech/03-109-e.html

[11] American Society of Heating, Refrigeration and Air Conditioning Engineers, Inc.

Properly oriented glazing and well-designed shading will help reduce solar heat gains in summer. When outdoor air temperatures are 30°C or less, whole house ventilation driven by wind speeds of 1 to 2 meters per second can remove unwanted heat generated by lighting and household appliances, as well as heat given off by the occupants during normal activities. Natural ventilation does this without consuming energy. Mechanical ventilation in the form of large low-pressure fans can also be used as a supplement to natural ventilation, particularly on hot, windless days. Non-mechanical cooling measures are described in detail in CMHC's Tap the Sun publication.

Building Envelope Measures

WINDOW SHADING

For south-facing windows, horizontal overhangs provide effective shading and limit heat gains in the spring, summer and fall. They are less effective on east- or west-facing windows because of the low angle of the sun, unless the projections are very wide, such as a carport or porch. Overhangs can be louvered, or fabric awnings as well as solid.

WINDOW TREATMENTS

There are a variety of add-on window treatments, including blinds, shutters, screens and drapes. Some treatments, such as window tinting and films, are integral parts of the glazing system. However, tints and films can cause a reduction of solar gains during the heating season. Internal shades can be adjusted to control summer heat gains and avoid the reduction of heat gains during the winter.

LOW E COATINGS FOR CONTROLLING SOLAR HEAT GAIN

‘Low-e’ refers to a coating that is applied to glass to block the absorption of heat energy. High-solar gain (hard coat) low-e coatings are typically used in Canadian climates to keep heat in, but low-solar gain (soft coat) low-e coatings, when applied to the inside face of the outer sheet of glass, reject solar gain thereby reducing cooling loads. Use hard coat low-e for the south and east orientations and the soft coat on north and west orientations.

ROOF ATTIC AND CEILING TREATMENTS TO REDUCE COOLING LOADS

The position of the sun means the roof is the home's major receiving surface for solar heat gain in the summer. Heat gain through roofs and ceilings can be reduced through radiant barriers, increased attic insulation and proper attic ventilation. "High albedo" roof finishes reduce cooling loads by reflecting solar radiation. These types of roof finishes also tend to last longer because the thermal expansion and contraction caused by heating and cooling of the roof is reduced.

REDUCING INTERNAL HEAT GAINS

Heat generated by lighting, appliances and people during the summer will contribute to the cooling load. By minimizing the use of electric lighting, particularly incandescent and halogen lighting, cooling loads are reduced. High efficiency, low energy consuming appliances save operating costs and tend to produce less waste heat than conventional appliances. Domestic water tanks and boilers should also be well insulated to reduce losses of unwanted heat to the house in summer.

Natural Ventilation

Operable windows equal to between 2 and 4 percent of the floor area should provide sufficient natural cooling, except on hot, humid, windless days. The following are ways to enhance natural ventilation.

- Cross-ventilation is best obtained by locating operable windows on opposite walls facing the upwind and downwind of the prevailing summer winds
- Casement windows are the best option as they provide the largest area of window opening
- The leeward (downwind) opening windows should be 50 to 100% larger than the windward windows
- Cross ventilation to work best, the depth of the home should be less than 5 times the ceiling height
- Adopt open-plan designs that have minimum restrictions to air movement

Using tall casement windows or locating operable windows with as much vertical separation as possible can also use the stack effect to induce air movement. Awning windows located close to the floor can work in conjunction with opening clerestory windows, cupolas or vents in the roof to maximize this effect.

WHOLE HOUSE FAN DRIVEN VENTILATION

In summer, it is better to ventilate the whole house with a supplementary fan than to use the furnace fan with modified ductwork that draws in outside air. The supplementary fan should change the inside air about 10 times an hour. It should be located at the highest point in the house, where it can vent the warmest air and allow cooler outside air to be drawn in through open windows below. Whole-house fans should be controlled by a cooling action thermostat or, better still, by an indoor-outdoor thermostat that keeps the fan from operating if the outdoor temperature equals or exceeds the indoor temperature.

CEILING FANS

By generating air movement of between 0.50 and 0.75 m/s, ceiling fans can provide a level of comfort equal to 2°C cooler in still air. High efficiency ceiling fans are now on the market that, due to their blade design, use less energy to move the required quantity of air. Some are also available that use photovoltaics and a DC motor, eliminating the use of purchased electricity.

THERMAL MASS

Thermal mass delays a dwelling's response to rising temperatures, keeping it cool except during prolonged hot spells. If cooler night air flows over heavy elements, such as concrete or masonry, it will help remove heat that has been stored there during the day and lower the temperature for the next day.

EVAPORATIVE COOLING

Air can be cooled, if it is relatively dry, through the evaporation of water. This has been done historically in gardens through the use of fountains and in buildings through the use of cooling towers.

High Efficiency Air Conditioning

Only after cooling loads have been minimized and other cooling methods described above have been used or eliminated from consideration should mechanical air conditioning be used. When a conventional air conditioner is used only units with a Seasonal Energy Efficiency Ratio (SEER) of 14 or higher should be considered. Air conditioning equipment should be sized for 80% of peak capacity for reasons of economy and operating efficiency. Using a cooling thermostat set point of 24 or 25^{o} C will also reduce the energy consumption for cooling.

For higher efficiency cooling and backup space and domestic water heating a ground source heat pump can be used. These can be up to two to three times more efficient than conventional air source heat pump / air conditioner but at a higher capital cost.

4.5 Secondary Energy Usage

Secondary energy use includes appliances, lighting and miscellaneous electric loads such as electronics, fans and gadgets. Appliances are similar to HVAC equipment, in that they are commonly replaced when they fail, in situations where necessity takes precedence over a deliberate decision. In addition, the loads associated with secondary energy uses are highly variable, being based in occupant lifestyle and product choices.

In a recent Building America report, it was noted that secondary energy uses (lighting, appliances and miscellaneous electric loads) are all heavily dependent on occupant behavior and product choices. ENERGY STAR® qualified appliances, lighting, electronics and fans are commonly included in energy efficient plans. The paper by Norton and Christensen notes that using EnerGuide or ENERGY STAR® qualified product label information, which is based on test conditions, lacks the level of detail and location specific information required that would help size PV systems for net zero energy homes. The paper goes on to outlines a prototype procedure for comparing appliance models in greater detail. This includes disaggrating machine electrical energy and hot water consumption as well as accounting for variability in incoming water temperatures for clothes and dish washers, modelling the interaction of clothes washers and dryers for any combination of these appliances, and accounting for a varying number of cycles per year.

An EPA document on high efficiency lighting offers a potential savings of 50% per light bulb switched to an occupancy sensor (Plympton et al, 2007). Energy efficient compact fluorescent lamps (CFLs) have been on the market for several years. The reductions in power demand and savings in lighting energy use due to CFLs are established benefits in retail and commercial settings; however, residential use of lighting is different from retail and commercial settings, with more selective use based on occupant needs.

Cost saving claims are typically based on the power consumption difference between CFLs and comparable incandescent bulbs, with no accounting for the ‘systems’ effect on space heating and cooling. A recent research document from Natural Resources Canada on compact fluorescent lights (CFLs) shows that during the heating season, CFLs can increase the space heating energy use, because of the corresponding loss in internal gains from incandescent bulbs. During the cooling season, the CFL reduces the space cooling demand and energy requirements. However, the overall there is a net energy saving in most cases, however the savings are reduced because of the interaction between heating systems and internal gains (NRCan, 2005). Looking at the bigger picture if the electricity is produced by a fossil fuel fired power plant the heat gains from lighting are equivalent to a 33% efficient furnace at best.

4.6 Stand-by Energy Usage

Stand-by energy usage has increased several times over in the last few decades, as electronic equipment has proliferated. Standby energy losses account for on average 4 to 11% of annual domestic electrical power consumption (Plympton et al, 2007). An effective low cost strategy for dealing with this problem is to plug appliances in a common power bar in each room that can be easily switched off. Legislation is already in place in California (as of January 2006) for maximum 1 Watt standing losses, and Australia has had voluntary regulations in place since 2000, with a target date of 2012 for all new products to have less than 1 Watt of stand-by energy use (EIU, 2006), In addition, the standing losses of electric water tanks can be reduced significantly through measures such as insulation blankets. Set back controls could save between 5 and 8% in electrical energy on electric water heaters (Plympton et al, 2007).

4.7 Household Energy Monitoring

Financial benefits of net zero energy retrofits can be brought to the forefront by home energy monitoring systems (Plympton et al, 2007, Parker, 2007, Kinney, 2007). Not only do home energy monitors point out the energy use (and financial costs) of a household, but pilot projects and demonstrations have shown that energy monitors can modify energy use patterns. Results have shown 10 to 25% reductions in energy loads (Plympton et al, 2007), and 12% reductions in greenhouse gas emissions (Thompson, 2006). Blueline Innovations of St. John's Newfoundland, the manufacturer of the units used in Ontario's Hydro One pilot project, indicates energy savings of 10 to 20% with their real-time monitors (EBM, 2007). Other options, such as dynamic pricing programs, could generate an average reduction of 4% in yearly electrical consumption and around 10% with effective feedback programs (Plympton et al, 2007).

Barriers to home energy monitoring systems have been twofold: few products are available that bundle controls for systems together in one product to display the information to homeowners in a useful manner, and the lack of communications standards for the various devices. Wireless technology and the emergence of national wireless standards for networking communication protocols may make it possible to incorporate customized energy monitoring and automation solutions in both new and existing homes. Scalable and modular, these systems would allow homeowners to make changes to the system in response to the changing needs of the household (Plympton et al, 2007). There are some issues with wireless systems and exposure to electromagnetic fields (EMFs) in the house (Fauteux, 2007).

4.8 Drainwater Heat Recovery

Drainwater heat recovery (DWHR) is a simple technology to reduce water heat demand. Drainwater heat recovery units take advantage of the fact that water clings to the sides of a vertical drainpipe due to surface tension, allowing heat to be recovered from the drainwater. Typical DWHR units are a length of copper drainpipe wrapped with a small diameter copper tube. Cold water circulates through the smaller tube to recover heat from shower drainwater. These units have been shown to reduce hot water energy requirements significantly. An energy-savings calculator for a variety of DWHR units was developed by Natural Resources Canada from the performance modelling and testing carried out during 2005 and early 2007. The calculator is due to be mounted on the Office of Energy Efficiency website.[12]

4.9 Solar Technologies

Solar Technologies can be broken out into three distinct streams: passive solar, solar thermal and photovoltaics (PV). Zero Energy Home documentation notes that solar technologies do not save energy, but should be considered an investment in an energy production that replaces conventional forms of energy. When solar technologies are added to homes that have undergone energy efficiency measures, the value of the investment is magnified (Merrigan, 2001). As a home's energy efficiency increases, solar options can offset more of the utility bills. The lower the load, the more the solar energy accommodates the overall energy requirements of a home. However, as a home becomes more highly insulated it is more prone to over heating and can accommodate less south glass with the same mass level. A less efficient home with a larger heating load can utilize more solar energy (in absolute terms) although the more efficient home with a smaller solar contribution will use less total energy. More solar energy can be utilized if additional effective thermal mass is added. (See table below). Up-front costs for solar thermal and PV systems can seem daunting, but in many cases, the costs are recouped over time on energy bills.

There are site-specific challenges associated with all solar technologies: orientation to the sun and shading taking precedence for all three streams (Henderson, 2006, USDOE, 2007, Kinney, 2006, Parker, 2007).

4.9.1 Passive Solar Design

Passive solar is the most difficult to include as a 'standard' technology. Passive solar cooling and heating are dependent on solar exposure, the level of energy efficiency attainable in the building envelope, window area, window technology and shading placement, the availability of thermal mass and effectiveness of

[12] From an unpublished research highlight carried out by Shawna Henderson for CMHC and Natural Resources Canada.

controls and destratification to reduce overheating. As such, it is not treated very clearly or profoundly in the literature reviewed.

Passive solar design includes using the building components to regulate temperature and optimize performance while avoiding such problems as overheating and glare. New construction offers the greatest opportunity for maximizing passive solar design, but any renovation or addition also offers opportunities for integration of passive solar heating or cooling. As is the case with new construction, it is important to include passive solar strategies as early as possible in the planning of any addition or renovation.

There are a few levels of solar planning and design. “Sun tempering” uses windows of a size and orientation to admit a moderate amount of solar heat in winter without special measures for heat storage. “Direct gain” or “high solar fraction” has more south-facing glass in occupied spaces and adequate thermal mass to smooth out temperature fluctuations. A sunspace addition keeps the glass and mass separate from the occupied space but allows for the transfer of useful heat into the building by convection or a common mass wall; temperatures in a sunspace are allowed to fluctuate outside of the comfort range.

Sun tempered designs in which the window area is correctly sized for the insulation levels of the home and the mass only consists of conventional wood frame construction solar contribution of up to 20% of the annual space heating can be expected. Where the mass level of the home is increased with effective thermal mass (masonry or concrete between 50 mm and 100 mm (2” to 4”) in thickness up to 40% solar contribution can be obtained. The two tables below show the window area to heated floor area ratios for ‘sun tempered’ and high-mass homes. The tables are from CMHC’s Tap the Sun publication (2007 revision).

Table 12: Sun Tempered Home, Maximum South Facing Window Area as Percentage of Heated Floor Area

	Building Envelope Energy Efficiency		
Location	**Nat. Bldg. Code**	**R-2000**	**Superinsulated**
Vancouver	6.5%	4.4%	3.2%
Edmonton	5.5%	3.4%	2.2%
Calgary	5.5%	3.4%	2.2%
Saskatoon	5.5%	3.4%	2.2%
Winnipeg	5.5%	3.4%	2.2%
Toronto	6.0%	3.9%	2.7%
Ottawa	6.0%	3.9%	2.7%
Montreal	6.0%	3.9%	2.7%
Quebec	5.5%	3.4%	2.2%
Moncton	6.5%	4.4%	3.2%
Halifax	6.5%	4.4%	3.2%
St. John's	6.5%	4.4%	3.2%

Table 13: High Solar Fraction Homes, Maximum Window Area as Percentage of Heated Floor Area Based on Double Glazed Clear Glass Window

	Building Envelope Energy Efficiency					
Location	**Nat. Bldg. Code**		**R-2000**		**Superinsulated**	
Mass level	*Medium*	*High*	*Medium*	*High*	*Medium*	*High*
Vancouver	8.0%	10.5%	5.6%	7.5%	4.1%	5.70%
Edmonton	7.0%	9.5%	4.6%	6.5%	3.1%	4.70%
Calgary	7.0%	9.5%	4.6%	6.5%	3.1%	4.70%
Saskatoon	7.0%	9.5%	4.6%	6.5%	3.1%	4.70%
Winnipeg	7.0%	9.5%	4.6%	6.5%	3.1%	4.70%
Toronto	7.6%	10.0%	5.1%	7.0%	3.6%	5.20%
Ottawa	7.6%	10.0%	5.1%	7.0%	3.6%	5.20%
Montreal	7.6%	10.0%	5.1%	7.0%	3.6%	5.20%
Quebec	7.0%	9.5%	4.6%	6.5%	3.1%	4.70%
Moncton	8.0%	10.5%	5.6%	7.5%	4.1%	5.70%
Halifax	8.0%	10.5%	5.6%	7.5%	4.1%	5.70%
St. John's	8.0%	10.5%	5.6%	7.5%	4.1%	5.70%

Medium mass level: Double layer of drywall + 38mm (1-1/2”) concrete floor topping
High mass level: Extensive brick and concrete

For retrofit projects, consider:

- Daylighting strategies, such as adding clerestories, sunpipes or interior windows
- Heat control techniques, such as adding exterior shades or overhangs, or seasonal shading such as hops or other fast-growing deciduous vine
- Using passive solar heating strategies (including long-term storage) to reduce overall heating loads
- Using passive solar cooling strategies such as solar chimneys to reduce or eliminate air conditioning needs

The synergy of different building components and systems need to be considered in passive solar design. Some questions to consider include:

- Can natural daylighting reduce the need for electric light?

- If less electric light generates less heat, will there be a lower cooling load?
- If the cooling load is lower, can fans or blowers be smaller?
- Will natural ventilation allow fans and other cooling equipment to be turned off at times?

4.9.2 Solar Thermal Systems

This section focuses on solar domestic hot water systems, as space and water combination systems are beyond the scope of this project. As the heating loads are reduced dramatically in zero energy homes, the cost-effectiveness of larger solar thermal systems drops in comparison to fuel-fired alternatives. However, it would be worthwhile to look further into combination systems where a fan coil uses the solar DHW return to augment an existing air handling system. Two examples of this type of approach are the Hanover House in New Hampshire, (solar DHW fan coil through a forced air furnace) or the Klingenberg Passivhaus in Illinois (a 100W electric resistance heater through high efficiency HRV) (Said, 2006). Several of CMHC's EQuilibrium House projects are also incorporating space and water combination systems that utilize solar thermal (CMHC-EQ, 2007).

In the Habitat for Humanity ZEH project in Denver, a 9 m^2 (96 s.f.) collector with 760L (200 gal.) of water storage was modelled. The results showed the system offered an 88% annual solar savings fraction (including pump energy use). The backup to the solar system is a natural gas tankless water heater that uses no heating energy when the solar water tank is at or above 46°C (115°F) hot water delivery temperature (electricity may be used in standby mode) (Norton and Christensen, 2006). The Hanover House (Hanover New Hampshire) includes a drainback system that acts as both a DHW system and a backup to the space heating system. The home designer notes that using more energy efficient motors in the solar system would save between 250 and 300 kWh annually (Saïd, 2006). Other methods of reducing solar DHW system electrical consumption are to use a PV powered pump or to use a thermosyphon system. Both of these approaches require the use of antifreeze solution in the solar collector and double walled heat exchangers.

There are several configurations of solar DWH systems, all of which include readily available manufactured components and/or packages. In Canada, these systems can reduce water heating loads by 50 to 60 percent on average (Henderson, 2006). With judicial load management, this percentage could be increased. To gain market acceptance, it is imperative to use a standardized system that is seen by both homeowners and builders as reliable, meeting standards and that has a comprehensive warrantee. Site-built units increase costs and reduce homeowners faith in the quality and durability of the systems (Henderson, 2006, Kinney, 2006, Norton and Christensen, 2006, Parker, 2007, USDOE, 2007). Optimizing the systems for location and occupant loads can be done through Canada's RETScreen software, among other methods and options.

Solar air heaters are usually used in conjunction with other solar thermal systems. Currently, solar air heating is available as room-by-room heaters and to pre-heat ventilation air, but applications are available to supply heat to the whole house. Slightly less efficient than solar water heaters, they are cost effective and popular in climates that remain cool for much of the year and have at least partial sunshine. Solar air heating systems don't freeze, making them an excellent option for colder climates (EERE, 2007). The RETScreen Solar Air Heating Project Model can be used to evaluate the energy production (or savings), life-cycle costs and greenhouse gas emissions reduction for ventilation air heating using transpired-plate solar collectors.

4.9.3 Photovoltaic Systems

Case studies of thirteen net zero energy homes in the US show PV systems to be between 2 and 5 kW capacity (USDOE, 2007). These homes are at lower latitudes than Canadian homes, resulting in higher power production due to higher insolation levels.[13] Canadian surveys and case studies of homes with grid-connected PV systems show a capacity range of 100W to 5 kW, with an average range of 1 to 2.5 kW. It should be noted that in general, these systems were not designed to create a net zero home, but were included in new home construction or in a renovation because of homeowner interest in reducing environmental impacts as well as reducing energy loads (Henderson and Bell, 2003, Henderson, 2004a). However, they do show that PV works in a Canadian setting to offset electricity loads.

Optimizing the size of a PV system includes reducing lighting, appliance and miscellaneous loads significantly, and then relying on occupant behavior to ensure that energy use is minimized. Miscellaneous

[13] Insolation refers to the average number of kilowatt-hours per square meter per day. The closer to the equator, the higher the level of insolation. For the weather and latitudes of the United States and Europe, typical insolation ranges from 4 kWh/m^2/day in northern climes to 6.5 kWh/m^2/day in the sunniest southerly regions.

loads are highly unpredictable and vary substantially from household to household (Norton and Christensen, 2006). Because of these factors, a PV system must be designed around an unknown largest load. To get around this, assumptions are based on the best available results from energy use studies, resulting in a system that is sized for a 'typical' household. If the household or weather is atypical, the home may not reach zero energy, or may be a net producer (Norton and Christensen, 2006).

4.9.4 Solar Ready

A solar ready home includes pre-planning for both solar thermal and PV systems. Plumbing, wiring and appropriate utility space for controls are included in the design phase. In a retrofit situation, this is trickier than a new home in the pre-construction phase, but where major renovations are taking place, the opportunity to include a low-cost rough-in for solar thermal and PV should be taken up. Where homeowners may not be able to include these systems in a deep retrofit due to costs, they may be able to afford them at a later date. Folding the cost of a solar thermal system into a re-financed mortgage has been shown to be one of the most cost-effective ways of affording this type of system: the slight increase in mortgage payments is offset by the savings in the energy use (Henderson, 2006).

5 Upgrades

In an ideal situation, with perfect solar potential and no budgetary restrictions, any of the house types included in this study could become a Net Zero House. However, that description fits only a few homes in Canada. What has been modelled for each house type is a highly insulated, well-sealed envelope and high-efficiency space and water heating systems that have the same delivery system as typically exists in these house types on a regional basis. High-efficiency motors, drainwater heat recovery, high-efficiency appliances and lighting, and reductions in stand-by power use round out the mix of energy efficiency measures included in the upgrade model. The contributions of the solar hot water and PV systems are added separately.

The upgrades were modelled based on the EQuilibrium Homes Initiative technical requirements[14]. This shows the method by which an enhanced EnerGuide for Houses rating can be reached.[15] This enhanced rating (designated as EGH*) allows for reductions in baseload electricity and hot water use as well as air conditioning and includes a credit for energy generation.

There are several different aspects to consider when carrying out a retrofit of this sort. Using the 'house as a system' metaphor, any change to one element of the house will affect how all other elements of the house perform. As well, there are considerations to take in terms of best practices, logical and cost-effective sequences and future planning. In many cases, homeowners will carry out these retrofit measures piecemeal, upgrading as they can afford to do so. A series of decision trees to use as an aid in planning a Net Zero Retrofit can be found at Appendix A. These decision trees start with the building envelope (foundations, walls, ceilings and windows) and end with mechanical systems. This sequence is crucial to a Net Zero retrofit, as the key to reducing energy costs effectively is to first limit the amount of energy required to operate the house. This translates into creating a highly insulated, well-sealed envelope that is durable, weatherproof and sustainable. This also makes sense in terms of extending the usable life of existing houses: the investment is put into the longest-lived components of the home, not into mechanical systems, which have a much shorter useful life. While it is better to upgrade the envelope from a long-term perspective, in many cases the quickest, easiest and least expensive way to reduce energy consumption is through upgrading the efficiency of the heating plant.

A well-managed building envelope retrofit can result in the need for much smaller heating equipment, so a high-efficiency unit can be considered when the existing unit is due for replacement. It must be noted that an improved envelope will often lead to lowered performance of an existing space heating system, as the change in load results in 'short cycling', where the unit cycles on and off quickly and cannot reach an efficient firing temperature. Heating contractors can offer interim solutions such as reducing nozzle sizes in oil-fired appliances.

Cooling equipment was included in the base case energy model for all house types in Toronto and Montreal. With the upgrades, the criterion for including cooling equipment was the benchmark from the EQuilibrium Housing Initiative: air conditioning was required only when the sum of the sensible load and latent load was greater than 1,500 megajoules (MJ) or 417 kWh. This sum, the annual cooling load, was not met in many of the upgrade models, so cooling equipment was not included in most of the calculations.

[14] as laid out in Appendix C of the Request for Proposals (RFP) for that project, dated 29 Nov 06. See www.cmhc-schl.gc.ca/en/inpr/su/eqho/index.cfm

[15] EnerGuide for Houses is a rating system for energy efficiency in Canadian houses. A rating of 0 being the worst case and 100 being a house that produces as much energy as it consumes in a year (a net zero house). This rating system can be used for both existing houses and new houses. Visit www. for more information on the program.

5.1 Upgrade Targets for Envelopes

The envelope insulation levels were determined for each city/region through discussion between team members and the advisory committee. The insulation levels for each city were based on experience; research into other low/net zero housing projects and the insulation levels that were used in the successful EQuilibrium House projects. The modelling was fairly generic; to show that the nominal insulation levels proposed could do the job. Proposed upgrades for a variety of ceiling and wall assemblies that would meet the upgrade targets listed below can be found in Appendix B and C. These include walls insulated from the exterior, walls insulated from the interior, a flat roof and a gabled roof.

AIR SEALING

Each of these upgrades includes a 50% reduction in air leakage rates, except for houses in Vancouver, where air leakage rates were highest. The air leakage rates in these houses were reduced by up to 70%, but not lower than 3.57 air changes per hour (AC/H) at 50 Pa pressure, which is considered the standard for conventional new construction. The other exceptions were all the houses built after 1995, in which case, the air leakage rate was brought down to the R2000 standard of 1.5 AC/H.

FOUNDATION FLOOR

Foundation floors were modelled as if a concrete slab was in place and insulation was added to the interior surface then covered with a subfloor and strapping. It was assumed that there is a limit to the amount of insulation that can be placed on top of a slab, as most basements have been, or will be, turned into living spaces, where homeowners desire the maximum ceiling height possible. If it were necessary to replace a slab or cover up a dirt floor, the basement could be excavated and a higher insulation value of up to RSI 4.6 (R 26) could be added to the foundation floor under the new slab.

FOUNDATION WALL

It was estimated that RSI 7 (R40) would work for most foundation wall applications. This was added in the model as interior wall insulation (assuming an unfinished basement). This would equate to 140mm (5.5 in) of foil-faced polyisocyranurate board, which would result in minimal loss of square footage for a finished basement. Full-height exterior rigid board insulation (approved for below-grade applications) could be added to enhance waterproofing if drainage work and regrading was being performed on a house.

RIM JOISTS/HEADERS

Rim joists and headers were modelled with the same insulation values as the above grade walls. In practice, they should be well sealed and insulated to *at least* the same level as above grade walls.

ABOVE GRADE WALLS

Above grade walls were modelled with spray polyurethane foam in a 2x4 or 2x6 cavity, with high-insulation value polyisocyranurate board to the exterior to make up the requisite insulation levels. Alternate wall assemblies can be found at Appendix B and C

EXPOSED FLOORS

Exposed floors were modelled with the same insulation level as above grade walls.

ROOFS / ATTICS

Three types of roofs were modelled in the upgrades: attics with flat ceilings (stick framed and manufactured trusses), sloped ceilings with no attic and 2x6 or 2x8 rafters, flat roofs with no attics and 2x6 or 2x8 roof joists. Insulation values were increased to suit the location. Sloped ceilings and flat roofs had rigid board insulation added on the interior and/or the exterior as required.

WINDOWS

All windows were upgraded to triple glazed units with low-e coatings. Where applicable, selective glazing was used, specifically heat mirror units (the same weight as double glazed units, with two panes of glass and one film between with low-e coatings). Regardless of glazing type, the window upgrades also included argon fill and insulating spacers in extruded fibreglass frames.

DOORS

Doors were all upgraded to metal doors with polyurethane cores bearing an ENERGY STAR® qualified mark.

Table 14: Modelled Envelope Upgrades, for All House Types

all insulation values are RSI (R)	Ceiling	Above Grade Walls	Exposed Floors	Below Grade Walls	Slab	Doors	Windows
Vancouver	8.8 (50)	4.6 (26)	4.6 (26)	4.6 (26)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers
Calgary	14.4 (80)	10.6 (60)	10.6 (60)	7 (40)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers
Toronto	10.6 (60)	7 (40)	7 (40)	7 (40)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers
Montreal	14.4 (80)	10.6 (60)	10.6 (60)	7 (40)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers
Halifax	10.6 (60)	7 (40)	7 (40)	7 (40)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers
Whitehorse	14.4 (80)	10.6 (60)	10.6 (60)	7 (40)	1.8 (10)	insulated metal	triple, 12mm low-e, argon fill, ins. spacers

5.2 Upgrade Targets for Mechanical Systems

SPACE HEATING

The systems chosen for modelling purposes require only a change of equipment, not delivery system. All units proposed are readily available. With improved building envelope, smaller heating loads offset the premium on the purchase price of a higher-efficiency heating unit. As all upgrades for fuel-fired furnaces include direct vent units, the flues can be blocked off. This helps improve air leakage levels significantly, as the 'chimney effect' will be lost. The heating load and the design heat loss may be reduced to the point where fuel-fired equipment cannot be found that is small enough to be properly sized for the house.

Where electric forced air systems are in place, such as in Montreal, an air-to-air heat pump was used to improve the performance of the heating system. In some cases where possible envelope improvements were minimal (such as in a pre-WWII, double-wythe brick home), a ground-source heat pump was used to decrease the overall energy load. Where heat pumps were specified, they also provide water heating.

Wood heating was not been considered in the upgrades, as there are too many variables involved to make an accurate model of the energy contribution from this source. Cooling was not required in most upgrade situations (as per the Equilibrium Housing Initiative benchmark of 1,500 MJ (417 kWh) cooling load).

WATER HEATING

Hot water was modelled as high-efficiency units augmented by closed-loop solar systems. The two systems considered in the upgrades –flat plate collector and evacuated tube collector -- are standard 'off the shelf' packages for domestic hot water that available across the country from various manufacturers and dealers. Solar hot water can be used in combination space and water heating systems with good results, but the systems are not consistent in their components or capacity across the country. Determining the energy contributions from these types of combination systems was not possible for this study.

VENTILATION

There are several ways to accomplish whole-house mechanical ventilation, as required by the National Building Code of Canada. The modelled upgrade meets the CSA F-326 room count model[16] with a heat recovery ventilator (HRV). This system preheats fresh air supply by recovering heat from stale exhaust air while keeping the two streams of air separate. High efficiency HRVs can recover up to 80% of the heat being exhausted from a building.

UPGRADE ASSUMPTIONS

- Space Heating - High temperature rise (5.5°C/9.9°F) ('normal' temperature rise = 2.8°/5.5°F)
  High efficiency motors and pumps included for all new equipment
- Space Cooling: capacity was determined by HOT2000™, with a SEER of 14
- Water Heating - Daily load = 150 L/person, 4 occupants (Base case daily load of 225 L/person, 4 occupants)
  Electric tank and solar storage tank (where applicable) have insulating tank blanket
  Oil/Gas fired systems have pipe insulation
  1.0 m (3.3 ft) drainwater heat recovery unit installed for 20% overall reduction in water heating load
- Ventilation –More efficient HRVs were chosen than the default HRV settings in HOT2000™, which are:
  125 W @ 0°C, 55% sensible heat recovery
  125 W @ -25°C, 45% sensible efficiency

Table 15: Modelled Mechanical System Upgrades for All House Types

	Space Heating	Water Heating	Whole House Ventilation	Add-On Renewables
Vancouver and Calgary	Condensing gas fired furnace (90% steady state efficiency)	Condensing gas fired tank (86% steady state efficiency)	A high- efficiency HRV was added to each house. Model	SOLAR HOT WATER

[16]To meet F-326, the mechanical ventilation capacity is based on specific air flows in liters per second or cubic feet per minute to each room or living area.

<table>
<tr><td>Toronto</td><td>Condensing gas fired furnace (90% steady state efficiency)
If no envelope upgrade, then 20kW (6T) GSHP COP = 4.9</td><td>Condensing gas fired tank (86% steady state efficiency) or off HP w/COP 1.91</td><td rowspan="3">and energy use dependent on house size and room count as per CSA F-326.

Most houses were serviced by a model that supplied 50 to 55 L/s, with the following energy use:
0°C = 117W,
80% sensible heat recovery
-25°C = 117W,
80% sensible efficiency

The larger house types (PreWWII 2-1/2 storey and 2storey w/basement) required a bigger model HRV to supply 65L/s, with the following energy use:
0°C = 150W,
79% sensible heat recovery
-25°C = 156W,
75% sensible efficiency</td><td rowspan="3">6m² evacuated tube

OR 12m² flat plate collector

WITH 240L storage

PHOTOVOLTAICS

Array size ranges with available roof area.

Range of potential energy generation in kWh per m² roof area:

Vancouver: 116 to 151
Calgary: 137 to 185
Toronto: 126 to 158
Montreal:128 to 160
Halifax:123 to 159
Whitehorse: 106 to 145</td></tr>
<tr><td>Montreal</td><td>10.5 kW (3T) Air-to-Air heat pump HSPF = 8.3
If no envelope upgrade, then 20kW (6T) GSHP COP = 4.9</td><td>Off either type of HP w/COP 1.91</td></tr>
<tr><td>Halifax
And
Whitehorse</td><td>Direct vent oil-fired furnace (87% steady state efficiency)
Whitehorse #2 upgrade: 10.5 kW gshp COP = 4.9</td><td>Tankless coil (0.82 energy factor)

Whitehorse #2 upgrade: off HP COP = 1.91</td></tr>
</table>

5.3 Upgrade Base Loads

The typical baseload in any house type as modelled in this study can be reduced by more than 60%, from 24 kWh/day to 10 kWh/day.

LIGHTING:

Increased daylighting through increased reflection from ceilings and walls (use semi-gloss/gloss white paint to bounce the light into the room). Other measures include adding reflective exterior surfaces (white stones or light coloured gravel under ground floor windows), skylights, clerestory windows and light shelves. Lighting controls can allow zoning of artificial light to complement daylighting.

APPLIANCES

Minimize or eliminate electric or gas dryer with clothesline or solar air collector dryer. Use electrical switching to reduce standby power consumption

Assumptions:

- Compact fluorescent and/or LED bulbs are used in all fixtures
- ENERGY STAR® qualified products brings the appliance load down to 4 kWh/day
- Standby losses can be reduced significantly through controllers.

Table 16: Baseloads for All House Types

	kWh/day	kWh/yr
Appliances	4.5	1640
Lighting	1	365
Other (electronics etc)	1.5	550
Exterior Loads	3	1095
Total base load (kWh)	10	3650
Total annual base load (GJ) (converted from kWh)		13.1

5.4 Solar Domestic Hot Water

A study of the performance of solar water heating systems that could be applied to the roofs and walls of existing homes across Canada was carried out using RETScreen SWH ver 3. The EQuilibrium technical requirements for hot water consumption of 225 liters per day @ 55°C were assumed. Systems were modelled based on the following variables. For each combination of variables the percent annual solar contribution and renewable energy in GJ was calculated. In addition the collector area and storage capacity required for systems to provide 100% solar was also calculated. A complete analysis of solar domestic hot water is included at Appendix F.
The most representative system of those typically installed today (2007) consist of 6 m^2 of collector and a 240 liter storage tank. In cloudy marine climates these systems are predicted to contribute between 38 and 48% of the annual hot water requirements for systems using flat plate collectors and between 59 and 62% for systems using evacuated tube collectors. In sunnier continental climates these systems are predicted to contribute 53% for systems using flat plate collectors and between 69 and 71% for systems using evacuated tube collectors.

HOT WATER CONSERVATION

The amount of hot water consumed in the home has a significant effect the total percent of the hot water the solar system can supply. The initial assumption used in modelling was that 225 liters per day at 55°C hot water would be used; this is based on the EQuilibrium program requirements. If this consumption can be reduced to 150 liter per day the same sized solar DHW system can contribute between 8 to 12% more of the total annual hot water requirements depending on orientation. Water conservation of course carries other benefits for the water supply system and the wastewater treatment system that service the home. In addition as water metering becomes more common water conservation will translate into direct economic benefits for the homeowner.

COMBINATION SYSTEMS
With larger collector arrays and larger storage systems the use of these systems to provide a portion of the annual space heating requirements in addition to domestic water heating presents itself particularly in the spring and fall. The modelling of the performance of these combination systems is beyond the capabilities of RETScreen at this time and therefore was not pursued but should be investigated at a later time for use in net zero buildings.

5.5 Photovoltaic Systems

An important component of net zero housing is the use of grid connected PV arrays mounted on the roof or wall of the home and/or on an auxiliary building. By sizing the PV array to generate as much electrical power on an annual basis as the house consumes and using the electrical grid in effect as a battery, net zero electrical energy consumption can be attained.

Case studies of thirteen net zero energy homes in the US show PV systems to be between 2 and 5 kW capacity (USDOE, 2007). These homes are at lower latitudes than Canadian homes, resulting in higher power production due to higher insolation levels.[17] Canadian surveys and case studies of homes with grid-connected PV system show a capacity range of 100W to 5 kW, with an average range of 1 to 2.5 kW. It should be noted that in general, these systems were not designed to create a net zero home, but were included in new home construction or in a renovation because of homeowner interest in reducing environmental impacts as well as reducing energy loads (Henderson and Bell, 2003, Henderson, 2004a). However, they do show that PV works in a Canadian setting to offset electricity loads.

Optimizing the size of a PV system includes reducing lighting, appliance and miscellaneous loads significantly, and then relying on occupant behaviour to ensure that energy use is minimized. Miscellaneous loads are highly unpredictable and vary substantially from household to household (Norton and Christensen, 2006). Because of these factors, a PV system must be designed around an unknown largest load. To get around this, assumptions are based on the best available results from energy use studies, resulting in a system that is sized for a ‘typical’ household. If the household or weather is atypical, the home may not reach zero energy, or may be a net producer (Norton and Christensen, 2006).

[17] Insolation refers to the average number of kilowatt-hours per square meter per day. The closer to the equator, the higher the level of insolation. For the weather and latitudes of the United States and Europe, typical insolation ranges from 4 kWh/m^2/day in northern climes to 6.5 kWh/m^2/day in the sunniest southerly regions.

Using RETScreen ver. P3, PV systems were analyzed in 14 Canadian cities (see Appendix G for detailed analysis). The kW peak (kWp) power ratings and areas for PV arrays were calculated for typical roof slopes and orientations. The arrays were sized according to kWp capacity and area to meet the electrical energy budget of 8760 kWh/yr. [18]

Systems sized to meet this load are, for the most part, too large for any of the available roof surfaces. Baseload reductions included in the energy upgrades indicate that the electrical energy consumption can be dropped to less than 4000 kWh/yr, with a corresponding reduction in the size of the PV system, to the point where most systems can be accommodated on a single, unobstructed roof face. The actual annual electrical energy consumption of any given household will vary with the efficiency of appliances, number and types of appliances, type of lighting and number of lighting fixtures as well as assumptions about the periods of operation.

[18] This an annual electrical energy budget was based on that developed for the NZEHH Pilot Demonstration Initiative (now called EQuilibrium Housing) technical requirements.

5.6 Example Calculation

The 1969 bungalow, located in Vancouver, is shown here as an example of how the various upgrades impact on a house. The following table shows more details, the main improvements are summarized below.

- Upgrading the insulation levels throughout the house dropped the design heat loss by nearly one-half, from 68.4 W/m^2 to 36.6 W/m^2, and improved the standard EGH rating from 53 to 72.
- Dropping the air change rate from 9.9 to 2.0 AC/H at 50 Pa dropped the design heat loss a further 3.3 W/m^2 and the EGH rating to 74.
- Installing high-performance windows reduced the design heat loss to 18.8 W/m^2 and improved the EGH rating to 80. At this point, the house has no ventilation system (but requires one) and still has the mid-efficiency gas furnace and water heater in place.
- Installing an HRV doesn't change the design heat loss but improved the EGH rating to 82.
- A high efficiency hot water system reduced the design heat loss another 0.6 W/m^2, and increased the EGH rating to 83.
- Taking out the mid-efficiency gas furnace and installing 4 kW of baseboard heaters brought the house to a 74% reduction in the design heat loss, from 68.4 to 17.6 W/m^2. The EGH rating improved to 86.
- From this point, the EGH* rating was used. The baseload was reduced, a drainwater heat recovery unit, a solar DHW system and a rooftop PV system were installed. These result in an EGH* rating of 94.
- Increasing the size of the PV system to produce the initial baseload of 8760 kWh/year brings the EGH* rating to 102, with an average surplus of 18.4 GJ, or 5111 kWh

The estimated annual space heating energy consumption for this upgrade was 4.3 GJ (1,184 kWh-e). The base case space heating estimate was 127.7 GJ (35,500 kWh-e with a 66.8% efficient gas furnace). It is known that an oversized mid-efficiency furnace leads to inefficient energy use, as the unit 'short cycles' and does not come up to steady state efficiency. A high-efficiency furnace for this upgrade would be sized as follows for this house:

Design Heat Loss * Heated Area * 1.4 sizing factor = Required Furnace Output

Therefore: 17.6 W/m^2 * 204 m^2 * 1.4 = 5,025 W (17,210 Btu) required furnace output.[19]

A quick scan of available high efficiency gas furnaces available in Canada shows models starting at 50,000 Btu output, nearly three times the size required for the house. High efficiency gas furnaces are not adversely affected by oversizing, but they do come with a premium price. The drastic reduction in space heating needs meant that instead of installing an expensive high-efficiency gas furnace, the existing mid-efficiency heating system could be replaced by 4.0 kW (based on a 1.25 sizing factor) of electric baseboard for 'backup' heat during the harshest days of the winter. This allows more of the retrofit budget to go to envelope improvements and renewable energy systems.

[19] The design temperature is based on the 97.5 percentile hourly temperature for a particular location based on historical weather data. In other words 97.5 % of all hours have a warmer temperature than this and 2.5% of all hours have temperature colder than this. CAN/CSA F280-M90 (R1998) specifies that the heating system shall be no more than 40 per cent larger than the heat required for the house at that design temperature. The 40 per cent allowance provides some margin for error in the calculation and also permits some oversizing to bring a house back up to temperature. Basically, this sizing calculation will recommend a furnace that runs at least 35-40 minutes every hour on the coldest day of the year.

Table 17: Progression of Upgrades for Vancouver Bungalow, c. 1969, in GJ

Base Case House EGH = 53															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
68.4	127.8		127.8	27.9		27.9	18.4	3.9	3.9	5.3	31.5	187.2	100%	--	--
Upgrade # 1: Increase basement insulation (RSI 7 walls, RSI 2 Floors) EGH = 68															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
45.4	71.7		117.1									176.5	94%	10.7	8%
Upgrade # 2: Upgrade envelope (RSI 7 walls, RSI 10.6 clg) AC/H stays at 9.9 EGH = 72															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
36.6	53.8		90.5									149.9	80%	26.6	21%
Upgrade # 3: Carry out air sealing work, AC/H = 2.0, at this point ventilation capacity of 24.8L/s is required EGH = 74															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
30.8	45.0	0.5	45.5									104.9	56%	45.0	35%
Upgrade # 4: Replace windows: triple glazed, low-e, argon fill units w/ insulating spacers and fibreglass frames EGH = 80															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
18.3	22.4	0.5	22.9									82.3	44%	22.6	18%
Upgrade # 5: Add HRV to carry ventilation needs EGH = 82															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
18.3	16.5	1.3	17.8									77.2	41%	5.1	4%
Upgrade # 6: Replace water heater w/condensing unit (gas-fired, 87% eff) EGH = 83															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
18.2	17.8	1.3	19.1	18.6		18.6						69.2	37%	8.0	29%
Upgrade # 7: Replace gas furnace with 4kW of electric baseboard heaters EGH = 86															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
17.6	4.3	0.8	5.1									55.3	30%	14.0	73%

Upgrade # 8: Add drainwater heat recovery, reduce water heating costs by 20%															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
				14.9		14.9						51.5	29%	3.7	25%
Upgrade # 9: reduce hot water use from 225/L day to 150/L day per person (4 occupants)															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
				10.0		10.0						46.6	25%	4.9	33%
Upgrade # 10: Add Solar Domestic Hot Water															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
				10.0	-6.1	3.9						40.5	22%	6.1	61%
Upgrade # 11: Replace appliances and lighting, drop base loads overall															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case		% due to u/g
							5.9	1.3	2.0	3.9	13.1	22.1	12%	18.4	58%
Upgrade # 12: Add PV array ($39m^2$*151 $kWhm^2$/yr) = 5889 kWh/yr or 21.1 GJ/yr) EGH* = 94															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
									-21.2		-8.1	0.9	1%	21.2	161%
Upgrade # 12a: Increase PV to produce 8760 kWh/year (31.5GJ) EGH* = 102. Net energy producer (surplus of 18.4 GJ = 5111 kWh)															
Design Heat	Space Conditioning			Water Heating			Baseloads					Energy Load		Red. @ upgrade	
Loss	Htg/Cool	Vent.	Total	Gas	Solar	Total	Appl.	Light.	Other	Ext Use	Total	GJ	% base case	GJ	% due to u/g
									-31.5		-18.4	-18.4	-10%	31.5	240%

Notes for this table:
Space conditioning includes heating and cooling as well as ventilation energy use.
Water heating: ‘solar’ is a negative number as it is on-site energy generation, replacing purchased fuel.
Base loads: PV is a negative number as it is on-site energy generation, replacing purchased fuel.
Under ‘Energy Load’ column, GJ refers to the overall house load, and is additive (i.e., each measure reduces the overall load). The % of base case indicates the drop of the overall energy load due to the upgrades
Under ‘Reduction due to upgrade’, GJ refers to the amount of energy saved by the specific upgrade. % Due to upgrade indicates the amount of energy not required due to the specific upgrade, and represents the drop in energy use by category, not by overall house load. Categories are space conditioning, water heating and baseloads.

Table 18: Summary of Overall rReductions in Vancouver Bungalow, c 1969, in GJ (with rooftop PV system)

	Base	Upgrade	Energy Requirement
	GJ	GJ	GJ
Space Conditioning	127.78	123.32	4.45
Water Heating	27.87	16.50	11.37
Baseloads	31.54	18.40	13.14
Solar DHW Contribution			6.13
PV Electrical Energy Contribution			21.20
Electricity Use: space cond. + baseloads			17.59
Less PV energy contribution			-21.20
Energy into the grid:			3.61
Water Heating Requirement (gas)			10.0
Less SDHW contribution			-6.13
Gas-fired energy for water heating:			3.9
Energy Deficit: difference between energy into grid and DHW load			0.29

Table 19: Summary of Overall Reductions in Vancouver Bungalow, c 1969, in GJ, (with PV system delivering 8760 kWh/annually)

	Base	Upgrade	Energy requirement
	GJ	GJ	GJ
Space Conditioning	127.78	123.32	4.45
Water Heating	27.87	16.50	11.37
Baseloads	31.54	18.40	13.14
Solar DHW Contribution			6.13
PV Electrical Energy Eontribution			21.20
Electricity Use: space conditioning + baseloads			17.59
Less PV energy contribution			-31.40
Energy into the grid:			13.8
Water heating requirement (gas)			10.0
Less SDHW contribution			-6.13
Gas-fired energy for water heating:			3.9
Energy Surplus: difference between energy into grid and DHW			17.7

5.7 Cost Effectiveness

This retrofit project is cost effective if the envelope and mechanical system upgrades, including the solar hot water system, can be carried out for $30,000 (assuming no rebates or incentives are in place). Repairs and maintenance costs for mechanical and solar hot water systems are not included in the following calculation. Adding this amount to a $150,000 mortgage has the following results:

Table 20: Financing a Net Zero Energy Retrofit with Solar DHW

$30,000 investment in retrofit measures (includes Solar DHW)	Increase in monthly payment	Decrease in monthly energy costs*	Difference
Vancouver			
Standard mortgage: 6% over 40 years	$163	$152	-$9/month
'Green' mortgage: 4% over 40 years	$124	$152	$28/month
Calgary			
Standard mortgage: 6% over 40 years	$163	$128	-$37/month
'Green' mortgage: 4% over 40 years	$124	$128	$4/month
Toronto			
Standard mortgage: 6% over 40 years	$163	$122	-$41/month
'Green' mortgage: 4% over 40 years	$124	$122	-$2/month
Montreal			
Standard mortgage: 6% over 40 years	$163	$121	-$42/month
'Green' mortgage: 4% over 40 years	$124	$121	-$3/month
Halifax			
Standard mortgage: 6% over 40 years	$163	$175	$12/month
'Green' mortgage: 4% over 40 years	$124	$175	$51/month
Whitehorse (with high efficiency oil fired heating system)			
Standard mortgage: 6% over 40 years	$163	$163	$0/month
'Green' mortgage: 4% over 40 years	$124	$163	$39/month

Note: the Whitehorse bungalow energy savings can be increased to $230/month if the envelope is fully upgraded and a 10.5 kW GSHP is installed. However, this would cost more than $30,000.
*based on prices retrieved from various utility websites in December 2007

Adding the PV system into the mix is more of a financial challenge. To reach the initial baseload of 31.5 GJ (8760 kWh) in Vancouver, the bungalow needs a system that is between 7.77 and 9.77 kW (peak capacity). As the baseload has been brought down substantially to 13.1 GJ (3638 kWh), the system can be resized as well. The roof area can accommodate an array of up to 5.2 kW (peak capacity) array, which would provide about 21.1 GJ (6040 kWh) of electricity. This 5.2 kW array would offset all annual electrical loads, and have an annual overall surplus of 3.6 GJ (1000 kWh). This surplus, which represents about 50% of the gas requirement for water heating in the Vancouver area, could result in an annual income/credit to the homeowner if a 'green power' incentive were in place.

Current prices for grid-tied PV systems in Canada run between $10 and $15 per installed Watt. A $20,000 investment results in a system sized between 1.3 and 2.0 kWp. Assuming the lower price can be met, a 2 kWp system would net approximately 8.34 GJ (2314 kWh). The baseload was reduced to 13.1 GJ (3650 kWh). This is not enough to bring the house to net zero electrical use: an additional 4.8 GJ would be required. However, PV systems are modular in nature and a further bank of panels can be added to the array in the future to complete the transformation to net zero. There is an increase in the monthly costs, although the additional cost for adding this size system onto this house would not be too daunting to add into a household budget, given that the additional cost is an investment in the long term, as opposed to ongoing (and increaseing) operating costs. As PV prices come down, and/or incentives are put in place for green power production, this option will become more viable. Repairs and maintenance costs for mechanical, solar hot water and PV systems are not included in the following calculation.

Table 21: Financing a Net Zero Energy Retrofit with Solar DHW and 2kW PV

$50,000 investment in retrofit measures (includes Solar DHW and 2kW PV system)	Increase in monthly payment	Decrease in monthly energy costs*	Difference
Vancouver			
Standard mortgage: 6% over 40 years	$272	$169	-$103/month
'Green' mortgage: 4% over 40 years	$223	$169	-$54/month
Calgary			

Standard mortgage: 6% over 40 years	$272	$149	-$123/month
'Green' mortgage: 4% over 40 years	$223	$149	-$74/month
Toronto			
Standard mortgage: 6% over 40 years	$272	$139	-$133/month
'Green' mortgage: 4% over 40 years	$223	$139	-$84/month
Montreal			
Standard mortgage: 6% over 40 years	$272	$132	-$140/month
'Green' mortgage: 4% over 40 years	$223	$132	-$91/month
Halifax			
Standard mortgage: 6% over 40 years	$272	$196	-$76/month
'Green' mortgage: 4% over 40 years	$223	$196	-$27/month
Whitehorse (with high efficiency oil fired heating system)			
Standard mortgage: 6% over 40 years	$272	$189	-$83/month
'Green' mortgage: 4% over 40 years	$223	$189	-$34/month

The underlying assumption is, of course, that the total cost of the energy ugprade and the solar DHW system and the PV comes to the dollar figures in the example above. This figure is over double the 'average' renovation figure of $12,000 reported by CMHC's study of renovation projects. However, it has been the project team's experience that homeowners are willing to pay more for what they want, witness the number of $20,000 to $100,000 kitchen renovations. At this time, an energy retrofit featuring solar DHW and PV on the rooftop cannot compete with the 'sexiness' of a major kitchen or luxury bathroom renovation.

AIR SEALING

This is the most inexpensive portion of the whole retrofit, and can often translate into energy savings out of proportion to the cost of carrying out the air sealing work. It should be done in conjunction with an energy audit and a blower door test to get an effective air-sealing job. A documented energy audit can also lead to a rebate from applicable incentive programs. Although a handy homeowner can do air sealing, most would be better off having it done by an experienced contractor. A 30% reduction in air change rate is about the best that can be expected in older houses without resorting to measures such as wrapping the existing shell with house wrap or polyethylene, or by using blown-in foam insulation. The retrofit upgrades included here have estimated a 50% reduction, based on these measures.

INSULATION

Insulation upgrades are more complicated in a Net Zero Energy Retrofit than a typical retrofit, and will prove to be higher cost, regardless of the assembly chosen (in most cases). Upgrading walls and ceilings to the proposed Net Zero levels will most likely be beyond the capabilities of the average homeowner. That being said, the energy savings will be higher than a typical retrofit as well.

Practically speaking, there are several opportunities for homeowners to reduce the costs associated with a Net Zero retrofit. A good example of this is when a house needs to have the siding replaced. This increase in wall insulation should correspond with upgraded windows.

As the exterior of the house is going to be stripped, insulation levels can be increased in several ways. Blown or sprayed insulation can be added to the wall cavities if necessary. The exterior of the house can be covered with one or more layers of insulating sheathing, or a 'Larsen Truss' can be constructed to create another deep cavity to be filled with insulation.

MECHANICAL SYSTEMS

Mechanical systems are often disregarded until they break down, and then the homeowner has to make a quick, usually uninformed, decision about replacing a furnace, boiler or hot water system. Getting past this 'crisis management' approach to a calculated and informed decision is probably the biggest challenge to reducing energy costs in an existing home. Higher efficiency units cost more to purchase, but operating costs are lower over the long term. If the replacement of a heating unit (furnace, boiler, etc) can be held until the building envelope has been upgraded, then the higher-efficiency unit can also be a smaller unit, therefore offsetting any premium on the improved performance. In some instances, envelope improvements will render a full-size heating system redundant, and a few well-placed electric baseboard heaters will suffice to carry the house through the harshest of winters. Another option is a direct vent gas fireplace to heat the main living space, with a baseboard in each of the bedrooms and bathrooms.

In the case of a heritage home or a home with a permanent cladding such as brick, there are very few upgrades that can be carried out on the envelope without compromising heritage value or aesthetics. In this case, a high-efficiency earth-energy system (such as a ground source heat pump, GSHP) can prove to reduce energy requirements significantly. Site conditions may allow the piping to be run vertically below the cellar of an older urban home, reducing the amount of land required to take advantage of such a system.

APPLIANCES

The cost-benefit of purchasing energy efficient appliances is well documented. The most cost-effective way of reducing base load electricity is to replace old appliances with new. The premium on the purchase price is more than balanced out by the savings in operating costs. The challenge for homeowners is, again, to be able to make the purchase price.

6 Energy Modelling Results

Sections 6.1 to 6.3 show reductions in both absolute numbers and percentages specific to space heating in each house type. Section 6.4 shows the solar contribution to the water heating. Section 6.5 shows an example of the calculation and Section 6.6 compares EGH* ratings for all houses in all cities.

6.1 Design Heat Loss

The following table shows the reduction in the design heat loss rates for each house type, as calculated by the HOT2000™ software. The design heat loss (here in W/m^2)[20] indicates how much heat the house will require to maintain a comfortable inside temperature in the most severe winter conditions for a given location.[21] For the sake of comparison, the table below also indicates a modified Passivhaus design heat loss standard for each city, based on heating degree days (HDD) under 18° C for each city. [22]

In most cases, where envelope characteristics did not limit insulation improvements, the heat loss was reduced by more than half, in some cases by up to three-quarters, of the base case house. Note that these figures are for an idealized situation using a hypothetical 'average' house, actual results will vary.

When looking at the modified Passivhaus standard, no house type upgrades in Vancouver met the 6.5 W/m^2 heat loss. As could be expected, in cities with colder climates, the modified Passivhaus standard was more likely to be met (4 house types in Calgary, 3 in Halifax and 4 in Whitehorse). Seven of the twelve house types in Vancouver were under 10 W/m^2, but only the older two-storey house upgrades in Calgary and Halifax were under the 10 W/m^2 target.

Three houses are of note in this table: the older two-storey home and both older and newer bungalows in Vancouver. Although they do not meet the modified Passivhaus heat loss target of 6.5 W/m^2, they do meet the 10W/m^2 target. Heat will only be required in these homes at the very coldest times of the year. For the better part of any given heating season, these buildings will carry themselves. In these three houses, the Vancouver envelope upgrades were boosted to the same levels as Toronto and Halifax (RSI 7 walls and RSI 0.6, RSI 7 below grade wall). As houses in Vancouver have higher air leakage rates than most houses in the rest of the country[23] the air change rate was dropped significantly, from 50 % of the base case AC/H rate (from 9 to 4.5 AC/H) to 2 AC/H or less.[24] In contrast, the two-storey house built to the National Building Code 1995 standard was modelled with RSI 4.6 walls and RSI 8.8 ceiling insulation and only a 50% drop in the base case AC/H rate. This shows the difference in the performance of the building envelope due to a well-sealed envelope with higher insulation levels.

[20] 1 W/m^2 = 3.4 Btu/s.f.

[21] The January design temperature for any major city or town in Canada is listed in the National Building Code under Appendix C: Climatic Conditions. It is defined as the lowest temperature at or below which only a certain small percentage (1% or 2.5%, depending on the application) of the hourly outside air temperatures in January occur.

[22] The standard Passivhaus design heat loss of 10 W/m^2 is based on Central European climatic conditions with up to 4000 HDD under 18° C.

[23] Based on house archetype information supplied by Natural Resources Canada, Vancouver houses had a median AC/H rate of 9.65 AC/H @ 50 Pa versus a national median of 6.6 AC/H @ 50 Pa

[24] The R-2000 standard for air leakage is 1.5 AC/H @ 50 Pa, the PassivHaus standard for air leakage is 0.6 AC/H @ 50 Pa

Table 22: Reductions in Design Heat Loss, W/m^2

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2 wood siding	Base	32.4	45.8	37.9	34.2	39.6	45.7
	Upgrade	7.5	17.0	13.1	17.3	13.8	19.8
	Difference	24.9	28.8	24.8	16.8	25.8	25.9
PWW2 brick veneer	Base			37.7	33.7	39.2	
	Upgrade			12.6	17.0	12.1	
	Difference			25.0	16.7	27.2	
PWW2 double brick	Base			40.7	38.5		
	Upgrade			22.7	26.8		
	Difference			18.0	11.7		
1-1/2 storey	Base	28.1	33.5	30.4	28.5	29.5	39.8
	Upgrade	11.8	14.1	12.6	16.8	11.5	19.8
	Difference	16.3	19.4	17.8	11.8	18.1	19.9
2 Storey 1988	Base	16.2	25.4	19.6	20.9	19.0	31.6
	Upgrade	7.1	8.3	15.7	14.2	9.9	16.0
	Difference	9.1	17.1	3.8	6.6	9.1	15.6
2 Storey 2000	Base	14.0	23.9	17.7	21.4	17.3	30.7
	Upgrade	9.1	12.5	10.2	11.5	10.2	15.6
	Difference	4.9	11.4	7.5	9.9	7.1	15.1
Bung 1969	Base	29.0	29.3	24.0	25.0	23.2	34.0
	Upgrade	8.2	13.8	11.1	12.5	10.7	19.9
	Difference	20.8	15.5	12.9	12.5	12.5	14.1
Bung 2000	Base	14.2	19.4	17.1	19.7	16.5	31.9
	Upgrade	8.3	12.8	10.5	11.5	10.1	16.4
	Difference	5.9	6.5	6.7	8.2	6.5	15.5
Split Level	Base	22.3	33.9	27.7	27.7	25.1	37.5
	Upgrade	11.0	17.8	13.9	14.7	13.7	21.5
	Difference	11.3	16.1	13.9	13.0	11.5	16.0
Split Entry	Base	19.3	30.8	23.0	23.5	21.3	33.5
	Upgrade	9.2	15.3	11.8	12.6	11.7	18.7
	Difference	10.1	15.5	11.2	10.9	9.6	14.8
Up/Down	Base	24.2	37.7	30.4	31.2	28.6	26.3
	Upgrade	11.3	18.2	15.8	15.0	14.3	12.6
	Difference	12.9	19.5	14.6	16.2	14.3	13.7
Rowhouse	Upgrade	20.3	31.9	25.6	26.6	24.3	
	Upgrade	9.5	15.7	12.0	12.8	12.8	
	Difference	10.8	16.2	13.6	13.8	11.4	
Passivhaus standard adapted to local HDD18° C	Local HDD	2950	5200	3650	4550	4100	6900
	Max htg load	6.5	13	9.1	11.4	10.3	17.3

Notes for this table:
The figures in column one indicate the average heated area in square meters for each house type.
The Passivhaus standard for heat loss design (bottom row of table) is based on 10 W/m2 in a central European climate with no more than 4000 heating degree days (HDD) at base 18° C.
Upgrades shown reflect changes in the heat loss design due to improvements in the building envelope. Heating systems would be sized base on these figures, with an oversizing factor based on the system specified.

6.2 Reductions in Space Heating Loads

In general, the upgrades resulted in significant reductions in heating loads in all house types, and in all cities, for an average reduction of 81% from the base house heating load (see Table 22). The overall range of reductions was from 56% to 96%. House type and age; typical construction patterns; and climatic differences between cities were all factors in causing variations in the reductions.

Across the country, the modelled reductions were highest in Vancouver, and lowest in Halifax, when GSHPs were included in Whitehorse. Where high-efficiency oil space heating equipment was used in Whitehorse, the reductions dropped below the Halifax figures.

Table 23: Range and Median Reductions in Space Heating Loads, by City (%)

	Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
Min	73%	74%	66%	57%	64%	56%
Max	96%	87%	90%	89%	95%	95%
Median	85%	81%	81%	84%	72%	75%

As shown in Table 23, the widest range of reductions by house type was found in the 1969 bungalow, where anywhere from 56% to 96% reductions were shown. This has to do with regional differences in construction and insulation levels, as well as climatic differences. The oldest homes showed the biggest reductions possible, based on an 'ideal' retrofit, where insulation and air sealing work could be carried out to the levels specified, and where the house was starting from the base case assumptions.

The percentage reduction does not show absolute reductions, in that a 90% median reduction in energy use for the Pre WWII house still results in higher space heating loads for this house type than in the bungalow, for example. This is not true in the case where GSHPs were included in the Whitehorse houses, where the higher efficiencies result in significantly lower heating loads. See Table 24 for complete listing of space heating loads for all house types in all cities, in absolute numbers and percentage reduction.

Table 24: Range and Median Reductions by House Type (%)

	min	max	median
PWWII: wood siding	84%	96%	90%
PWWII: brick veneer	83%	86%	84%
PWWII: double brick	83%	90%	87%
1 - 1/2 storey	72%	87%	83%
2 storey 1988	72%	93%	84%
2 storey 2000	68%	95%	75%
Bungalow 1969	56%	96%	83%
Bungalow 2000	57%	92%	70%
Split Level	62%	86%	77%
Split Entry	65%	87%	82%
Up/Down Duplex	70%	87%	76%
Row House	70%	89%	80%

Table 25: Reductions in Space Heating Load, in GJ, for All Cities

	Vancouver			Calgary			Toronto			Montreal			Halifax			Whitehorse		
	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.
PWWII: wood siding	174.4	6.2	96%	195.9	28.0	86%	187.9	29.5	84%	109.0	16.9	85%	204.6	9.7	95%	195.7	12.7	94%
PWWII: brick veneer							186.6	25.5	86%	106.7	16.6	84%	201.7	34.7	83%			
PWWII: double brick							208.7	20.4	90%	130.3	21.6	83%						
1 - 1/2 storey	117.9	15.9	87%	116.7	14.6	87%	121.2	20.5	83%	74.7	13.2	82%	110.9	22.5	80%	143.8	41.0	72%
2 storey 1988	87.6	7.8	91%	119.1	15.8	87%	101.5	18.9	81%	71.0	15.8	78%	100.6	28.3	72%	163.2	12.0	93%
2 storey 2000	62.8	17.2	73%	95.0	22.5	76%	73.9	19.7	73%	76.8	12.0	84%	102.2	33.1	68%	295.2	13.8	95%
Bungalow 1969	126.2	5.1	96%	102.6	17.8	83%	89.8	15.2	83%	64.7	8.2	87%	87.9	22.0	75%	123.2	54.5	56%
Bungalow 2000	32.4	7.3	77%	47.0	12.0	74%	37.3	12.8	66%	40.4	17.3	57%	49.1	17.5	64%	108.9	8.8	92%
Split Level	97.3	17.4	82%	130.5	30.3	77%	110.7	24.5	78%	80.6	11.1	86%	101.5	34.2	66%	154.7	59.4	62%
Split Entry	79.0	10.6	87%	113.7	19.9	82%	89.9	16.8	81%	62.6	7.9	87%	77.7	24.6	68%	124.9	44.2	65%
Up/Down Duplex	84.5	19.1	77%	128.1	29.0	77%	114.5	34.4	70%	91.0	11.7	87%	122.6	36.8	70%	107.3	27.1	75%
Row House	64.5	10.8	83%	95.2	19.2	80%	86.2	25.5	70%	69.4	7.8	89%	94.3	26.5	72%			

6.3 Climatic Differences

Table 25 shows the difference in terms of energy consumption between the initial envelope upgrade and the second envelope upgrade retrofits in Vancouver, as well as the unchanged upgrade for the 2 storey house built to NBC 1995. It can be seen that the newer house, because of existing insulation values and air leakage rates, has a smaller percent reduction than other houses, although the overall reduction in energy consumption in GJ puts it in the same range as the other primary upgrades for houses in this area.

Table 26: Space Heating Energy Consumption (GJ), Vancouver Envelope Upgrades (selected house types)

	Vancouver #1 RSI 4.6 walls, RSI 8.8 clg, 50% AC/H reduction			Vancouver #2 RSI 7 walls, RSI 10.6 clg, 1.5 or less AC/H		
	Base Case	Upgrade 1	% Red.	Base Case	Upgrade 2	% Red.
PWWII -wood siding	174.4	15.0	91%	174.4	6.2	96%
1 - 1/2 storey	117.9	24.0	80%	117.9	15.9	87%
2 storey 1988	87.6	12.7	86%	87.6	7.8	91%
2 storey 2000	62.8	23.1	63%	--	--	--
Bungalow 1969	126.2	11.1	91%	126.2	6.5	95%

Note that the figures shown are for energy consumption (Gigajoule, GJ), not design heat loss (W/m^2)

It was found that, regardless of the high insulation values, most houses in Whitehorse did not come close to meeting the target EGH* 90 rating or higher with an improved envelope and higher efficiency heating system. A change in mechanical systems brought selected houses to a higher EGH* rating. In the houses listed in the table below, the oil-fired forced air system was changed to a 10.5 kW ground source heat pump with a COP of 4.9[25] Insulation levels stayed the same as for the initial upgrade. Following are four house types with this second upgrade.

Table 27: Comparison of Space Heating Energy Consumption (GJ), Whitehorse Heating System Upgrades

	Whitehorse #1 RSI 10.6 walls, RSI 14.4 clg, 50% AC/H reduction			Whitehorse #2 RSI 10.6 walls, RSI 14.4 clg, 50% AC/H, GSHP		
	Base Case	Net Zero	% Red.	Base Case	Net Zero	% Red.
PREWWII wood siding	195.7	59.8	69	195.7	12.7	94%
2 storey 1988	163.2	62.6	62%	163.2	12.0	93%
2 storey 2000	195.2	58.9	70%	195.2	13.8	93%
Bungalow 2000	108.9	38.7	64%	108.9	8.8	92%

6.4 Solar Contribution to Water Heating

The solar contribution to water heating was modelled as if there was a clear south facing roof area. In Appendix F, calculations are shown for solar contribution for east or west facing roofs, with the acknowledgement that there will be a reduction in the efficiency of a system mounted on a roof with either of these orientations. The figures below show optimal solar contribution for south and east or west facing roofs,

25 that GSHPs typically operate with a COP of 2.5 to 3.9. The higher COP used here is based on the US DoE website indicating best available high-efficiency heating systems. Actual performance may be lower because of climatic conditions.

taking into consideration the roof slope typical for each house type as indicated in Table 2. The solar contribution was subtracted from the total space and water heating loads of each upgrade. See Appendix D for tables showing final space and water heating loads.

Table 28: Optimal Solar Contribution to Water Heating (GJ)

	Vancouver		Calgary		Toronto		Montreal		Halifax		Whitehorse	
	South	W/E	South	W/E	South	W/E	South	W/E	South	W/E	South	W/E
PREWW II	6.5	5.5	9.9	7.4	8.3	6.8	8.2	6.5	8.2	6.6	7.7	6.2
1 -1/2 Storey	6.6	5.4	10.1	7.4	8.5	6.7	8.2	6.4	8.3	6.5	7.9	6.2
2 Storey	6.1	5.6	8.8	7.2	7.8	6.8	7.6	6.6	7.7	6.7	6.9	6.0
Bungalow	6.1	5.6	8.8	7.2	7.8	6.8	7.6	6.6	7.7	6.7	6.9	6.0
Split Level	6.1	5.6	8.8	7.2	7.8	6.8	7.6	6.6	7.7	6.7	6.9	6.0
Split Entry	6.1	5.6	8.8	7.2	7.8	6.8	7.6	6.6	7.7	6.7	6.9	6.0
Up/Down Duplex	6.3	5.6	9.4	7.3	8.1	6.8	7.9	6.6	8.0	6.7	7.2	6.1
Row House	6.5	5.5	9.7	7.4	8.3	6.8	8.1	6.5	8.2	6.6	7.4	6.0

6.5 Base Loads

Base loads were dropped as noted in section 5. See Appendix D for tables showing total base loads compared to overall energy loads. Reducing baseloads further could happen on a household-by-household basis, but the variation in baseloads due to lifestyle has to be kept in mind.

6.6 Best Case Example: The Bungalow

In general, the bungalow house type has the best characteristics for a net zero energy upgrade. This is because of the typically simple structure and shape.

The single storey structure means that heat loss at rim joist/header areas is at a minimum, compared to other house types, and that in older bungalows with unfinished basements, these areas are easily reached. The simple ‘box with a lid’ shape of these houses means fewer corners and other difficult areas to insulate. Unlike with an older home, such as the Pre-WWII types, there is little chance that there will be an issue with changing the exterior of the building, as few of these houses will have exterior heritage value, or double-wythe brick walls. There may be brick veneer on the front elevation, in which case a mix of interior and exterior insulation improvements could take place. If the brick veneer is in poor condition due to spalling or other damage, it could be replaced, with an increased exterior insulation layer below the new cladding.

These houses have a long and narrow profile, resulting in a potentially larger single, unobstructed roof face for solar add-ons such as hot water and PV systems. The limitation with the bungalow house type is orientation. The long axis of the house would have to face the southern quadrant to optimize the solar potential. However, the calculations in the appendices show that east and west exposures also warrant analysis when looking at solar hot water and PV installations.

The table below shows the overall energy reductions and possible GHG reductions for a bungalow in the various cities.

Table 29: Reductions in Energy Requirements for the Bungalow, All Cities (GJ)

	Vancouver		Calgary		Toronto		Montreal		Halifax		Whitehorse	
	BASE	NET ZERO	BASE	NET ZERO	BASE	NET ZERO	BASE	NET ZERO	BASE	NET ZERO	BASE	NET ZERO
space & DHW	154.1	16.9	132.9	30.8	117.8	27.7	85.6	14.1	128.5	35.3	143.7	15.3
Reduction	137.1	GJ	102.1	GJ	90.1	GJ	71.5	GJ	93.2	GJ	128.5	GJ
	38078	kWh-e	28360	kWh-e	25029	kWh-e	19862	kWh-e	25897	kWh-e	35682	kWh-e
Appliance	33.1	13.7	33.1	13.7	32.8	13.7	32.1	13.7	33.0	13.7	33.6	13.7
Reduction	19.4	GJ	19.4	GJ	19.2	GJ	18.4	GJ	19.3	GJ	19.9	GJ
	5400	kWh-e	5401	kWh-e	5320	kWh-e	5109.6	kWh-e	5368	kWh-e	5530	kWh-e
GHG Emissions, Tonnes, CO_2												
Base Case	12.7	6.6	11.6	7.1	10.8	6.9	17.6	7.3	14.3	8.7	22.5	13.9
Reduction	6.0		4.5		4.0		10.3		5.6		8.7	

6.7 Comparison of EGH Ratings

The EGH* ratings for three variations are shown below. The first column shows the EGH* rating with only solar DHW added to the upgraded house types. The second column shows the 'full' PV array, one that will supply 8760 kWh/ annually to the house in a given location. The third column shows the rating resulting from a solar DHW system with a smaller rooftop PV array, which varies in size according to the potential roof area available from each house type. The annual energy generated by the PV systems as calculated through RETScreen was subtracted from the total energy use as calculated by HOT2000™.

It can be see that only houses with the 'full' PV array actually get to EGH* 100 with the typical upgrades. Looking at the Whitehorse column, it can be seen that only one of the house types (an up/down duplex with a full PV array) comes close to the EQuilibrium House Initiative threshold of EGH*90. Very few of the houses in all cities come to the EGH*90 threshold with solar DHW only, but they do fare better with both solar DHW and a smaller PV system. The next table shows the EGH* ratings for Vancouver and Whitehorse, with the second round of upgrades in place, namely more insulation and a lower air leakage rate in Vancouver, and a ground source heat pump in place of a high-efficiency oil-fired forced air system in Whitehorse.

Table 30: Comparison of EGH* Ratings

	Vancouver			Calgary			Toronto			Montreal			Halifax			Whitehorse		
	SDHW ONLY	PV ONLY	PV + SDHW	SDHW ONLY	PV ONLY	PV + SDHW	SDHW ONLY	PV ONLY	PV + SDHW	SDHW ONLY	PV ONLY	PV + SDHW	SDHW ONLY	PV ONLY	PV + SDHW	SDHW ONLY	PV ONLY	PV + SDHW
PREWWII A	89	97	90	86	93	88	84	92	86	89	98	91	93	**101**	95	74	81	75
PREWWII B							86	93	87	89	98	91	83	90	84			
PREWWII C							90	97	91	87	96	89						
1 - 1/2 storey	86	94	88	90	97	92	87	94	89	90	99	93	87	94	89	81	88	83
2 storey 1988	89	98	92	90	97	93	88	96	90	89	98	92	85	92	87	74	82	77
2 storey 2000	86	94	88	87	94	90	87	95	90	91	**100**	94	83	91	86	75	83	78
Bungalow 1969	90	98	92	89	96	91	89	97	91	92	**101**	95	87	94	89	77	84	79
Bungalow 2000	95	**100**	93	90	98	93	90	98	92	89	98	91	88	96	90	82	89	83
Split Level	88	96	90	85	92	87	86	94	88	91	**100**	93	83	90	85	75	83	77
Split Entry	90	98	91	88	95	90	88	96	90	92	**102**	94	86	93	87	80	87	81
Up/Down Duplex	87	96	88	85	92	87	83	90	84	91	**100**	92	82	90	83	86	93	87
Row House	90	98	91	89	95	90	86	93	87	92	**102**	94	85	93	86			

Notes for this table:
The EGH* rating includes space and water heating, reduced hot water and base electrical loads.
Any EGH* rating of 100 shows a net zero energy house, over 100 shows a net energy producer.
Any EGH* rating under 90 would not have qualified for the CMHC EQuilibrium Housing Initiative.
Column 1 under each city shows the EGH* rating with a standard solar DHW system installed.
Column 2 shows the EGH* rating with a PV array that will produce 8760 kWh/annually
Column 3 shows the EGH* rating with solar DHW and a PV array sized to the roof area for each house type

It can be seen in this table that nearly all of these houses crack the EGH*90 threshold with solar DHW only (with the exception of the 1 –1/2 storey in Vancouver, which comes in at EGH*88). However, none of them really come close to net zero as defined by the EQuilibrium Housing Initiative (EGH*100) without the addition of a PV system that is larger than the rooftop area available for the average size of each house type. However, several house types do get a rating over EGH*100, most notably the newer bungalow, with EGH*106. Ratings above 100 mean that the house could be a net energy producer, especially in years with mild winters in Vancouver. The GSHP does well for the Whitehorse houses, bringing them well above the EGH*90 mark in general.

Table 31: Comparison of EGH* Ratings with Round 2 Upgrades
(Vancouver envelope and Whitehorse heating system)

	Vancouver				Whitehorse			
	SDHW ONLY	PV ONLY	RooftopPV + SDHW	Full PV + SDHW	SDHW ONLY	PV ONLY	RooftopPV+ SDHW	Full PV + SDHW
PREWWII A	89→93	97→**100**	90→93	**102**	74→92	81→**100**	75→93	**102**
1 - 1/2 storey	86→88	94→97	88→90	99	--	--	--	--
2 storey 1988	89→91	98→99	92→93	**101**	74→92	82→**100**	77→95	**102**
2 storey 2000	--	--	--	--	75→92	84→99	78→94	**101**
Bungalow 1969	90→92	98→**100**	92→94	**102**	77→93	84→**101**	79→95	**103**
Bungalow 2000	95→91	**100→104**	93→97	**106**	82→93	89→**101**	83→95	**103**

Notes for this table:
The EGH* rating includes space and water heating, reduced hot water and base electrical loads.
Any EGH* rating of 100 shows a net zero energy use model, over 100 shows a model that is a net energy producer.
Any EGH* rating under 90 would not have qualified for the CMHC EQuilibrium Housing Initiative.
Column One under each city shows the EGH* rating with a standard solar DHW system installed.
Column Two shows the EGH* rating with a PV array that will produce 8760 kWh/annually
Column Three shows the EGH* rating with solar DHW and a PV array sized to the available roof area for each house type

7 Discussion of Findings

7.1 Envelope Changes

Changing the building envelope has repercussions on how both the building and the mechanical systems perform. The improved building envelope results in much smaller heating loads. This means that both passive solar and internal gains represent a larger portion of the total heating supply. While the usable proportion of passive solar and internal gains increased significantly with the envelope improvements, the absolute value of each, as measured in GJ, actually decreased in most houses. This is explained by the lower solar heat gain co-efficient of high-performance windows with no corresponding increase in window area, and by less heat being generated by appliances and lighting. The range of usable passive solar gain doubled, starting at 5 to 12% and increasing to 10.5 to 23%, while the percentage of usable internal gains in some cases tripled, from 19% to 59%.

The improved levels of useable passive solar and internal heat gains have a significant impact on the sizing of the heating system and are also affected by measures taken to reduce baseload electricity use. Replacing old appliances with ENERGY STAR® qualified products, and substituting compact fluorescent bulbs for incandescent bulbs will reduce baseloads, but will also reduce the amount of energy these fixtures contribute to internal gains. Determining the impact that baseload reduction measures have on internal gains is not as easily quantified as the impact of envelope improvements on overall energy loads. The EGH* rating allows for reductions in baseloads and hot water use, but does not quantify the change in the internal gain fraction.

Reductions in air leakage rates (i.e., tighter envelope) will result in the need for additional mechanical ventilation in most houses. Existing heating systems become oversized as the heating load is dropped significantly, reducing the efficiency of the existing equipment without any alterations to nozzle size.

The reductions in the design heat loss show that even with these sizable upgrades, most house types modelled do not meet the Passivhaus standard or the modified standard for Canadian cities shown in Table 22. This can be attributed in part to a pair of envelope factors: the air leakage rate and the insulation levels at the foundation. The air leakage rate is probably the more significant of the two.

Most upgrade models dropped the air leakage rate by 50%. Table 4 (page 31) shows the average air changes per hour at 50 Pa in Canadian house types, with the maximums ranging from 8.4 to 12.3, and the minimums ranging from 2.9 to 9.65. With a median AC/H rate of 6.6 at 50 Pascals, this 50% reduction resulted in upgraded air leakage rates well above the R-2000 standard of 1.5 AC/H at 50 Pascals, let alone the air change rate of 0.6 at 50 Pascals as required by the Passivhaus standard. As the modelled figures are assuming that a high-quality level of air sealing work was done, these reductions could be seen as being optimistic.

Some Passivhaus projects have insulation values in the foundation slab and the foundation walls that well surpassed the modelled insulation in the upgrades. For instance, the Minnesota Passivhaus (a dormitory on the Concordia University campus) has RSI 9.43 (R 54) under the slab and RSI 10.9 (R63) walls, while a duplex in Oslo, Norway has RSI 12.2 (R 70) under the slab and RSI 9.1 (R 52) walls. The slab and basement wall upgrades modelled in this study were limited to RSI 1.8 (R 10) and RSI 7 (R 40) respectively.[26]

7.2 Mechanical Systems

In several houses in Vancouver, the heating system requirements are so low that there is no equipment available that can be properly sized for the house. Where space heating will be required for only a small fraction of the year, appropriate approaches might be to fit the house with inexpensive baseboard heaters or a heating coil in the HRV supply duct and run an energy deficit in harsh winters, and a surplus in mild winters. The heating coil could be electric or hydronic, drawing from the domestic hot water tank.

[26]Information on the Minnesota and Oslo houses was retrieved on December 17, 2007 from www.passivhausprojekte.de/projekte.php?search=2. This site houses a database of certified and registered Passivhaus projects throughout the world.

Conversely, the Whitehorse houses performed the poorest for space heating reductions. Higher insulation levels might improve this somewhat. Changing from an oil-fired system to a ground source heat pump may be the best solution, but will not work in all areas due to site-specific requirements (enough land, proper hydrology, etc.). Looking at the bigger picture, the actual coefficient of performance (COP) of the ground source heat pump can be linked to the source of the electricity used. For example, if the electricity to power the GSHP is from a fuel-fired source such as a diesel generator, the maximum efficiency of the conversion from diesel to electricity is 33% and delivered efficiency will be lower, about 25 to 30%. In this scenario, a GSHP with a COP of 3 is ends up performing like a high efficiency furnace or boiler but at a much greater capital cost.

In-floor radiant heat is an extremely popular choice for new housing, and can work in retrofit situations. It was not modelled in this study primarily because the 'standard' heating systems in Canada for several decades have been forced-air, baseboard hydronics and electric baseboard. Thus, most of the existing housing stock has been set up to run these systems. In determining cost-effective ways of getting to net zero energy in this study, it was felt that revamping the heat delivery system was not part of the equation. That being said, low-temperature in-floor heat is a very efficient and effective heat delivery system, with more versatility than a dedicated forced-air system, as it can use many different fuel sources singly or in combination. It is a choice that should be looked into when planning a retrofit. In-floor heating can be in direct conflict with passive solar heating, so where the use of passive solar is desired this must be accounted for.

7.3 Materials and Product Selection Considerations

When making choices about products and assemblies that revolve around sustainable housing some of the following issues should be taken into consideration:

- Embodied energy and embodied pollution (how much energy is used and how much pollution is created by the material or assembly from the mining or harvesting stage through manufacturing, transport and delivery to the demolition and disposal/recovery of the material or assembly).
- Sustainably harvested wood or plant material. Look for local sources as well. Start within 100 miles of your site and move out from there.
- High post consumer recycled material content
- Material / product service life
- Potential for future recycling of material when service life completed
- Assembly service life

7.4 Valuing Non-Energy Benefits

One aspect of whole house (or 'deep') energy efficiency retrofits that is not currently addressed is the value of the associated 'non-energy benefits' (NEBs). In general, energy saving programs ignore these benefits, or do not use a comprehensive methodology for determining them. According to Thorne, comfort and aesthetic benefits far outweigh energy concerns, and very few homeowners assess the economic benefits of their investments by monitoring energy bills or calculating payback times (Thorne, 2006). Besides comfort and aesthetics, identified non-energy benefits include health and safety, noise reduction, education-related and convenience (automatic thermostats, easier maintenance). Other benefits include greater control over energy use, reduced sick days, ease of selling home, enhanced pride and prestige, improved sense of environmental responsibility and enhanced peace of mind and responsibility for family well-being (Thorne, 2006). In a study carried out by CMHC, participants indicated top priorities in home upgrades were improving comfort and lowering operating costs. Reduced environmental impact and improved indoor air quality were lower priorities (Thompson, 2006). All of these NEBs should be taken into consideration in a Net Zero Energy Retrofit program.

8 Conclusions

The modelling in the study is based on best-case scenarios all around: well-done air sealing and insulation work, ease of access to all parts of the house, reducing labour costs, unobstructed south faces on roofs for PV and solar DHW systems and homeowners who can carry out both the hot water usage and baseload reductions indicated in the study. Homeowner behaviour and lifestyles drive these last two aspects, making them difficult to quantify accurately. That being said, there are some conclusions to be made:

As could be expected, there were differences between climatic regions that influenced the challenge of approaching net zero energy in existing houses. The other factor that was clearly a challenge was the house type itself, where the age, styles of construction and ease of upgrading the envelope came into play.
The climatic region where retrofits were most likely to come close to net zero energy mainly through building envelope improvements was Vancouver and environs. Whitehorse, even with significant increases to the envelope, required a high-efficiency GSHP to approach net zero energy in any house type. The other cities and climatic regions fell into the range between Vancouver and Whitehorse.

The house type that would most easily be retrofitted to net zero energy could be the bungalow, where the simple form of the building allows for better results from air sealing and insulation work. In addition, the long axis of the house gives the potential for a larger, unobstructed or shaded south-facing roof area than would be possible for other house types. This gives the potential for the largest possible roof-mounted PV array and solar domestic hot water system, even if the roof typically is not at optimum slope for these technologies in most Canadian regions. Other houses, such as the pre-World War II house, with a 9/12 pitch, which is much better for solar optimization, have a smaller potential south-facing roof that most likely has a dormer or other shading obstacle on it. A possible future topic for research could be analyzing various Canadian cities for the solar potential of the housing stock.

Barriers to actually getting to net zero energy in existing homes include the challenge of coordinating the timing of a retrofit. Making a project cost-effective depends on some planning – for example, if the siding is to be replaced on a home, that is the time to insulate the exterior and upgrade windows. Mechanical equipment is usually replaced under emergency situations, so a change-out to a higher-efficiency, smaller output unit that coordinates with an envelope upgrade requires a clear plan and timely financing. Other barriers are based in the logistics of finding contractors willing and able to do the work required.

The technology and materials are available to reduce energy loads significantly, in existing houses, by a factor of 7 to 9. However, getting to net zero energy in existing houses is completely dependent on the cost of the add-on renewable systems that take the house to net zero energy. Solar thermal systems are market ready and can be proven to have a reasonable payback period, and are more readily accepted as an option by homeowners. If there were financial incentives and mechanisms in place, roof mounted solar thermal systems would become a much more commonplace sight in Canadian neighbourhoods. PV systems are currently very expensive, with very long payback periods for small systems. Until there are reasonable incentives to purchase and operate these systems (tax rebates, purchase incentives, ‘green power’ premiums for grid-connected systems), it will be very expensive for any householder to create a net zero energy home from his or her existing dwelling.

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Web-based Resources

Architecture 2030
A voluntary challenge to architects and the building industry to reduce energy requirements in new buildings by 30% by 2030.
www.architecture2030.org/
Viewed Aug 19, 2007

Affordable Comfort Institute
ACI hosts an annual conference and has an extensive list of resources
www.affordablecomfort.org
Viewed Aug 10, 2007

Building America http://www.eere.energy.gov/buildings/building_america/
Covers projects and publications produced as part of the Building America Project
Viewed Aug 17, 2007

Cost Efficient Passive Houses as European Standards
Conference and limited technical information on passive house concept for new and renovated buildings
http://www.cepheus.de/eng/index.html
Viewed Aug 21, 2007

Houses without Heating Systems, 20 low energy terrace houses in Göteborg
http://www2.ebd.lth.se/avd%20ebd/main/Gothenburg/Folder_Lindas_EN.pdf
Viewed Aug 21, 2007

International Energy Agency (IEA) Solar Heating and Cooling Programme
http://www.iea-shc.org/
Viewed Aug 17, 2007

International Energy Agency (IEA) Energy Conservation In Buildings And Community Systems
Vast array of publications and information on IEA sponsored activities related to energy conservation in buildings
http://www.ecbcs.org/
Viewed Aug 17, 2007

International Energy Agency (IEA) TASK 28 - SUSTAINABLE SOLAR HOUSING
Provides summaries of numerous passive solar single and multifamily homes constructed in Europe.
http://www.iea-shc.org/task28/index.html
Viewed Aug 21, 2007

International Energy Agency Task 37 - Advanced Housing Renovation with Solar and Conservation
The results of the Task will be brochures and technical reports describing: Housing segments with the the greatest multiplication and energy saving potentials [A] Design and performance of exemplary renovation projects, describing benefits, process and motivations [B] Packages of technically and economically robust concepts for housing renovation which could be applied in concrete projects [C] Innovative future solutions with great potential of primary energy reduction [C] A “basics” on sustainable renovation including principles for the design and realisation of renovation projects, connecting the technical point of view at the project scale to factors of a larger scale (environment and resources, infrastructure and equipment, health and well-being) [D] *Strategies for increased market penetration of housing renovation [A]*
http://www.iea-shc.org/task37/
Viewed Aug 21, 2007

Low Impact Housing
A database of over 200 international low impact housing projects, ranging from single-family homes to complete city plans. Primarily cold-climate construction.
www.lowimpacthousing.org
Viewed Aug 28, 2007

National Affordable Housing Network http://nahn.com/
US non profit devoted to providing information on affordable housing, provides house plans emphasizing energy efficiency
Viewed Aug 17, 2007

The Renovation Roadmap
Site associated with the Canada Home Builders Association (www.chba.ca)
www.myhomereno.com/english/makeyourhomeenergy/
Viewed Sep 5, 2007

Scandinavian Homes Ltd.
Scandinavian highly insulated wood frame houses utilizing passive solar heating and SDW constructed in Ireland

http://www.scanhome.ie/passive.php

Solar Today Magazine May / June 2005
The Near Zero Energy House
http://www.solartoday.org/2005/may_june05/ZEH.htm
Viewed Aug 21, 2007

10 Appendices

Appendix A: Decision Trees

The following decision trees are laid out in an order that would produce an optimal Net Zero Energy Retrofit, starting with the building envelope from the foundation up, and then turning to the mechanical systems. A decision tree (or tree diagram) is a tool that graphically models decisions and their possible consequences. A decision tree is used to identify the strategy most likely to reach a goal, in this case, a whole-house Net Zero Energy Retrofit, although they have been broken into major sections as below.

Below Grade Retrofits

- Basement Cellar Foundation Floor
- Basement Cellar Foundation Walls
- Preserve Interior Finish Basement Walls
- Crawlspace
- Slab on Grade

Above Grade Retrofits

- Walls No Heritage Value
- Preserve Exterior Wall Finish
- Preserve Interior Wall Finish
- Preserve Interior and Exterior Wall Finish
- Windows
- Roofs
- Preserve Exterior Roof Form and Finish
- Preserving Interior Ceiling Finish
- Passive Solar Space Heating

Space Heating Systems

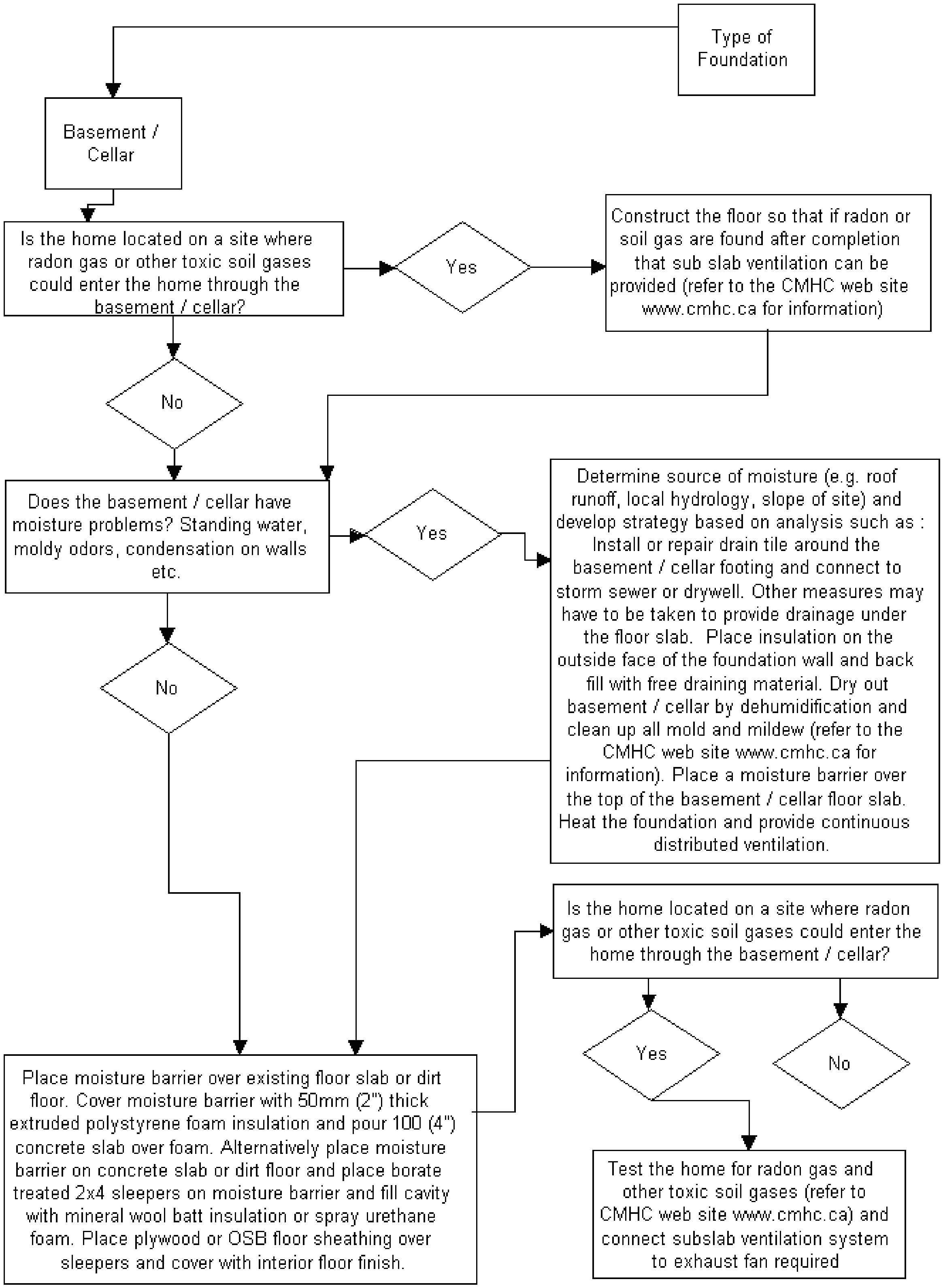
- Heating Systems
- High Efficiency Furnace or Boiler
- Gas Furnace
- Ground Source Heat Pump

Ventilation Systems

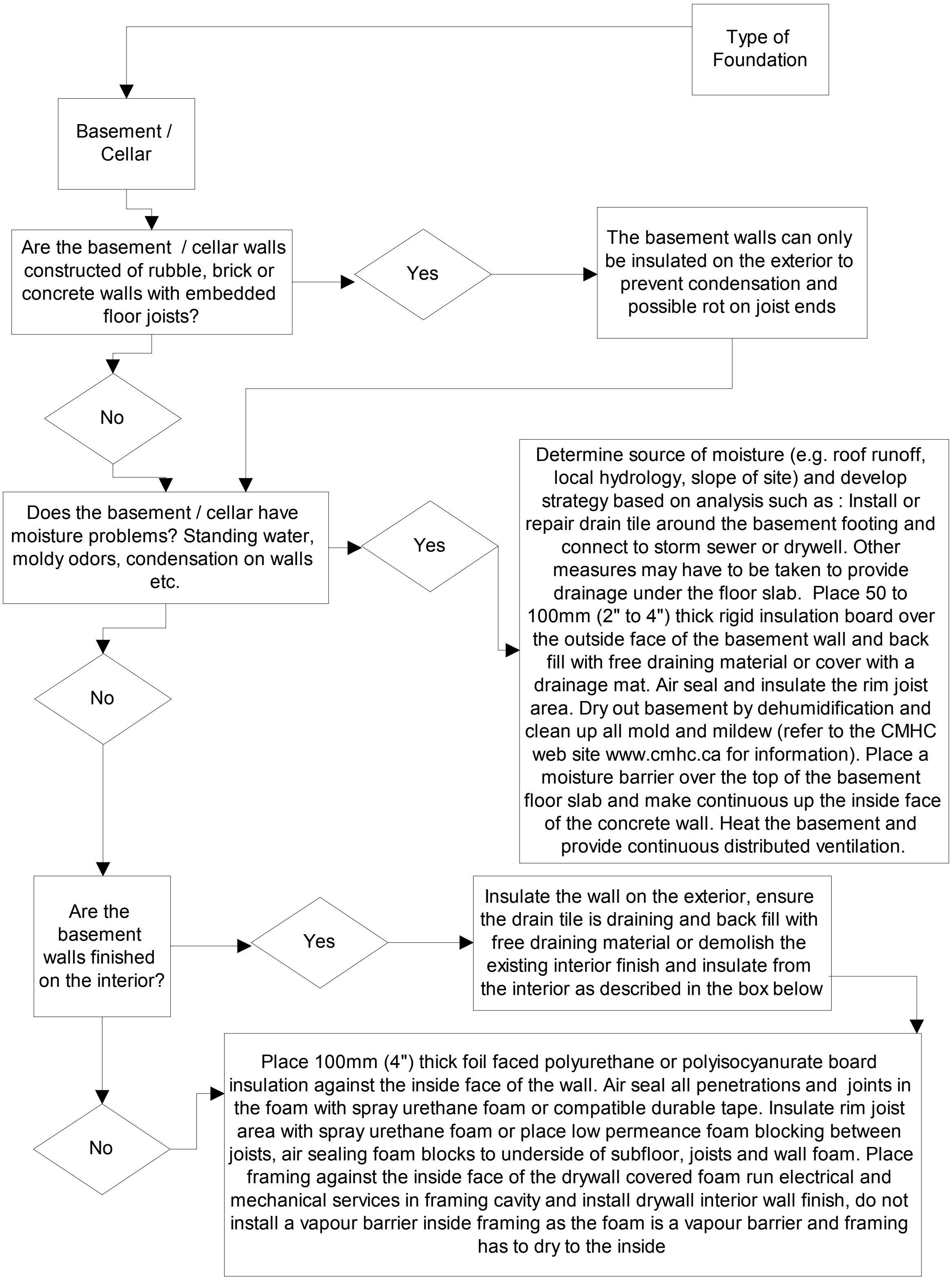
Water Heating Systems

- Gas Domestic Water Heating System
- Oil Domestic Water Heating System
- Electric Domestic Water Heating System

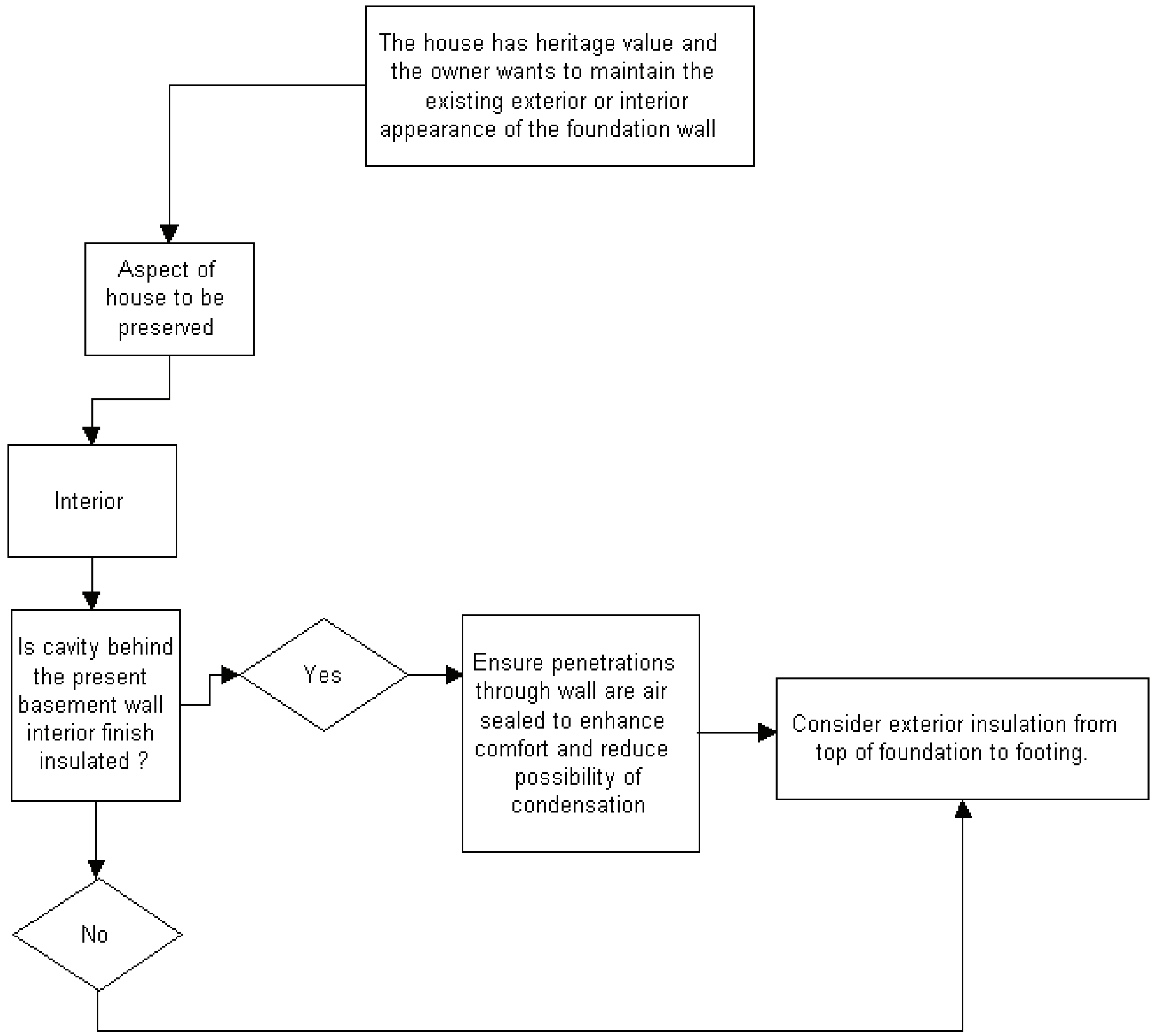
Basement Cellar Foundation Floor



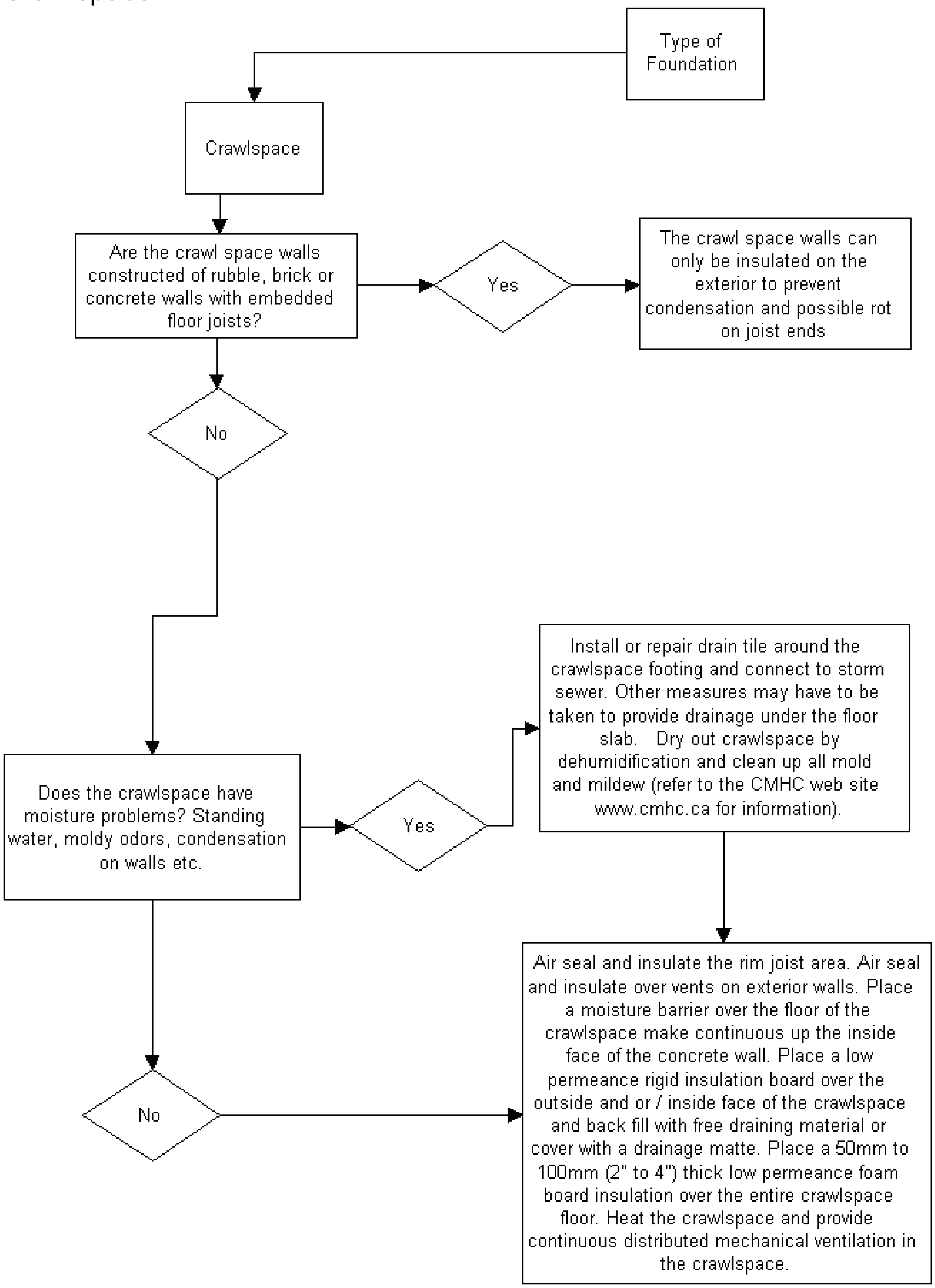
Basement Cellar Foundation Walls



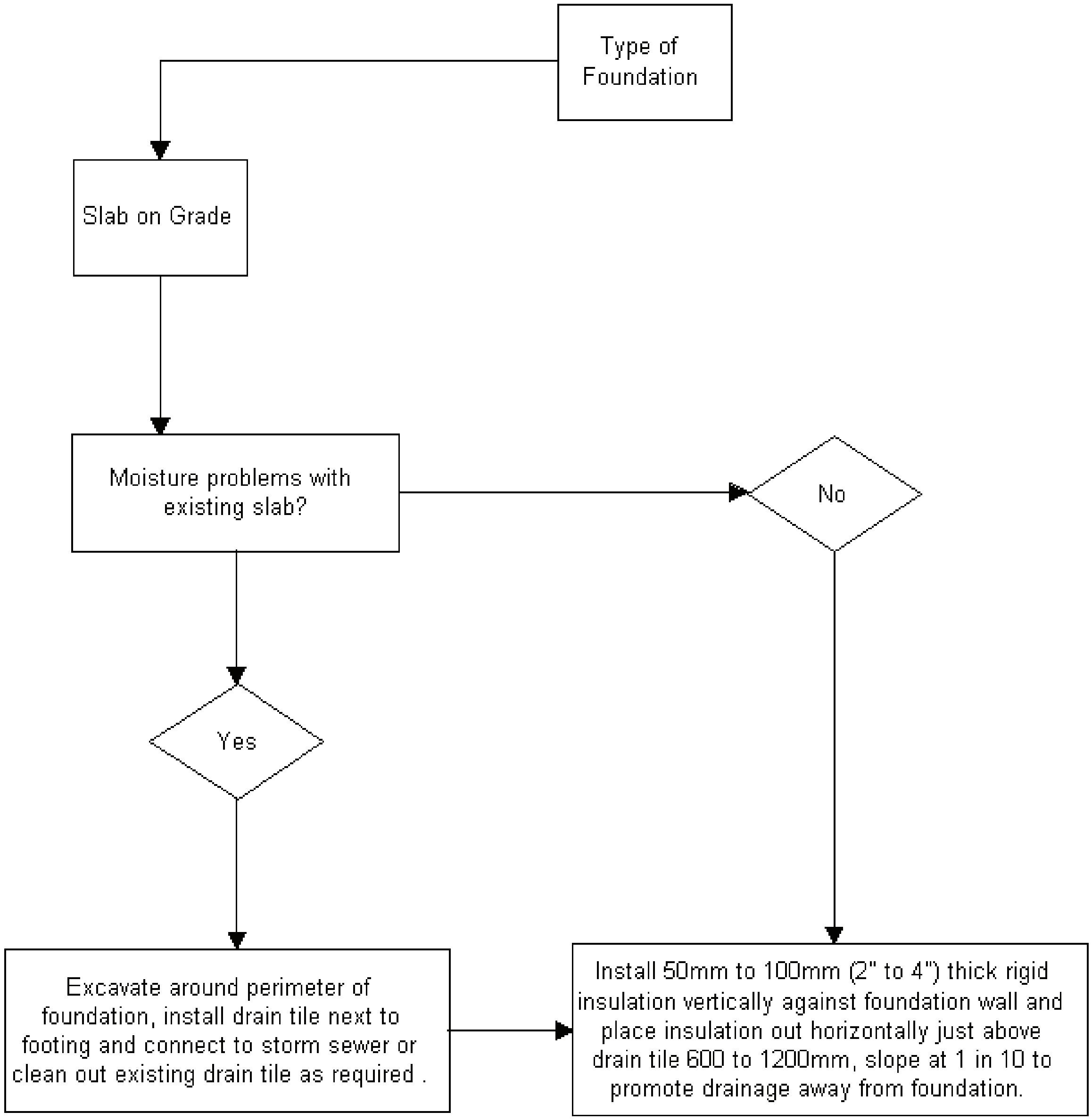
Preserve Interior Finish Basement Walls



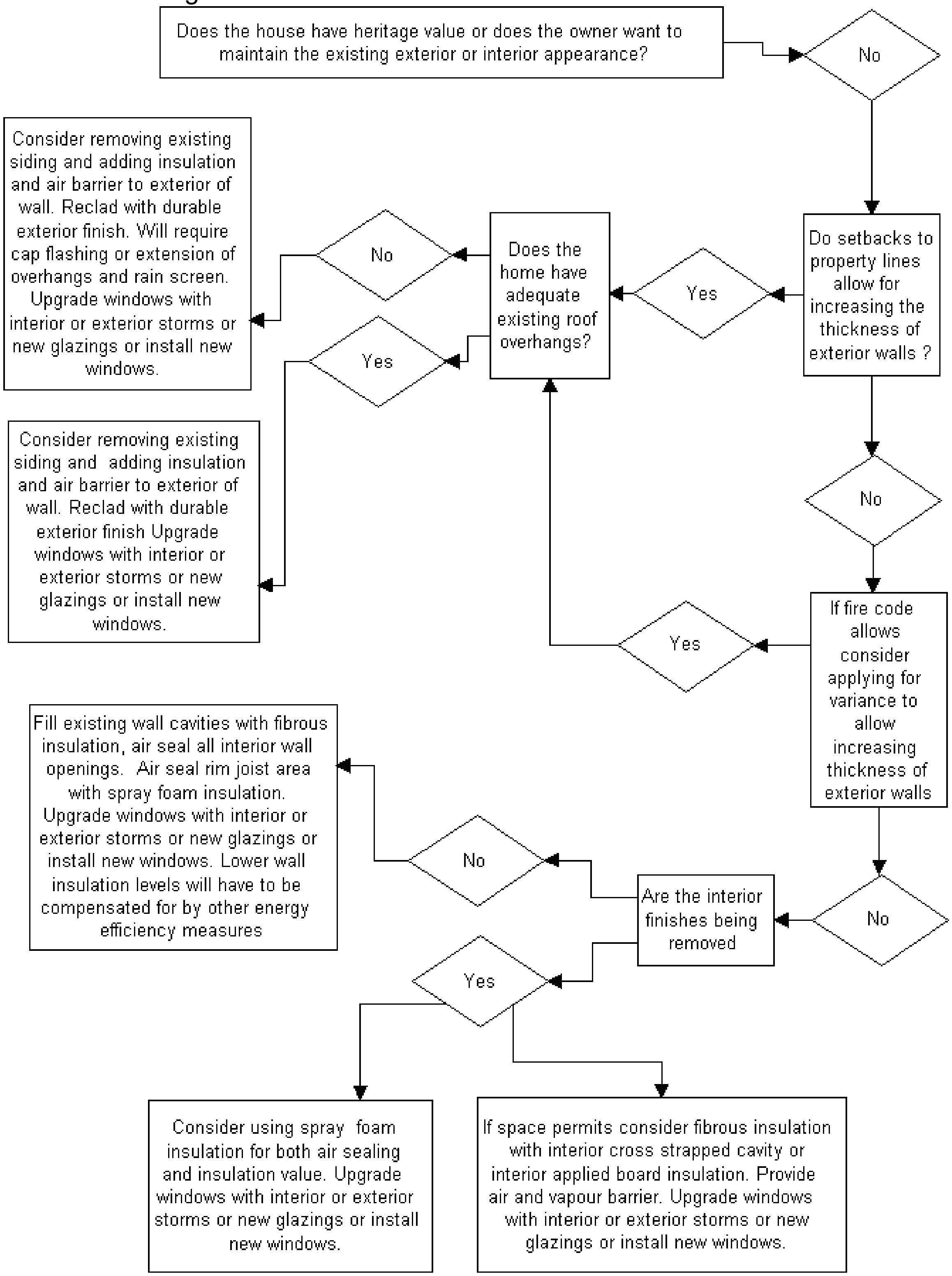
Crawlspace


Type of Foundation
Crawlspace
Are the crawl space walls constructed of rubble, brick or concrete walls with embedded floor joists?
Yes
The crawl space walls can only be insulated on the exterior to prevent condensation and possible rot on joist ends
No
Does the crawlspace have moisture problems? Standing water, moldy odors, condensation on walls etc.
Yes
Install or repair drain tile around the crawlspace footing and connect to storm sewer. Other measures may have to be taken to provide drainage under the floor slab. Dry out crawlspace by dehumidification and clean up all mold and mildew (refer to the CMHC web site www.cmhc.ca for information).
No
Air seal and insulate the rim joist area. Air seal and insulate over vents on exterior walls. Place a moisture barrier over the floor of the crawlspace make continuous up the inside face of the concrete wall. Place a low permeance rigid insulation board over the outside and or / inside face of the crawlspace and back fill with free draining material or cover with a drainage matte. Place a 50mm to 100mm (2" to 4") thick low permeance foam board insulation over the entire crawlspace floor. Heat the crawlspace and provide continuous distributed mechanical ventilation in the crawlspace.

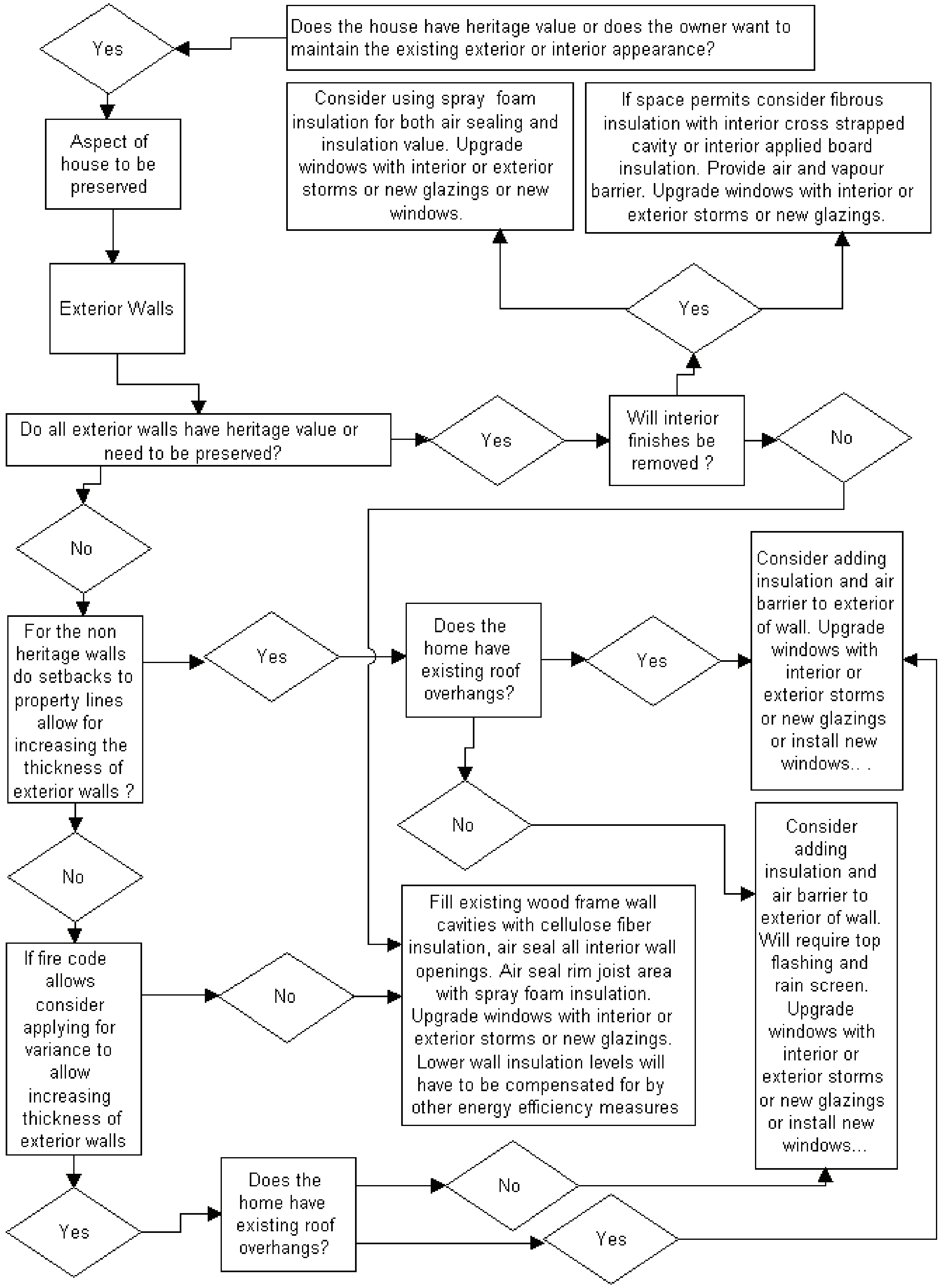
Slab on Grade



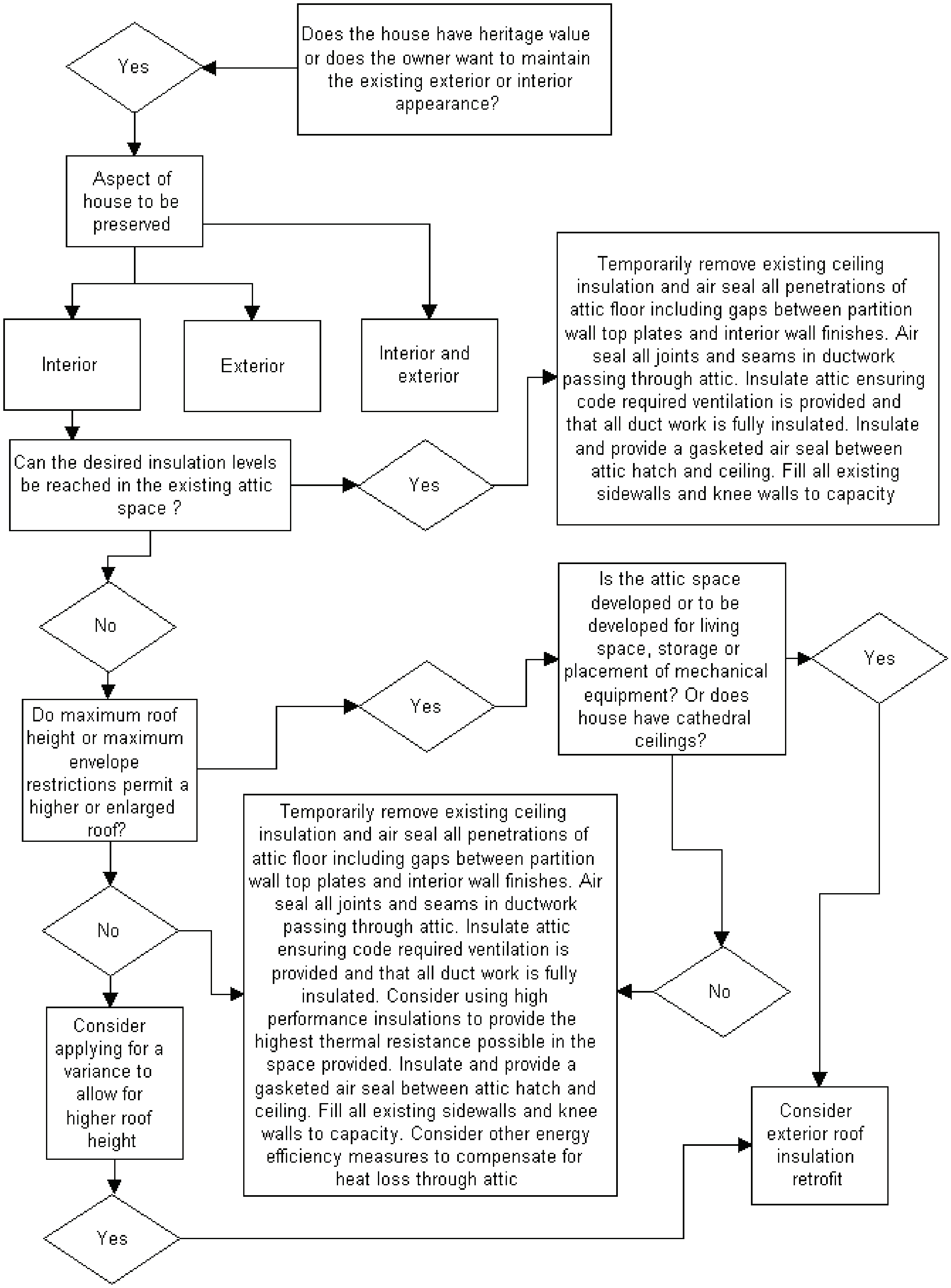
Walls No Heritage Value



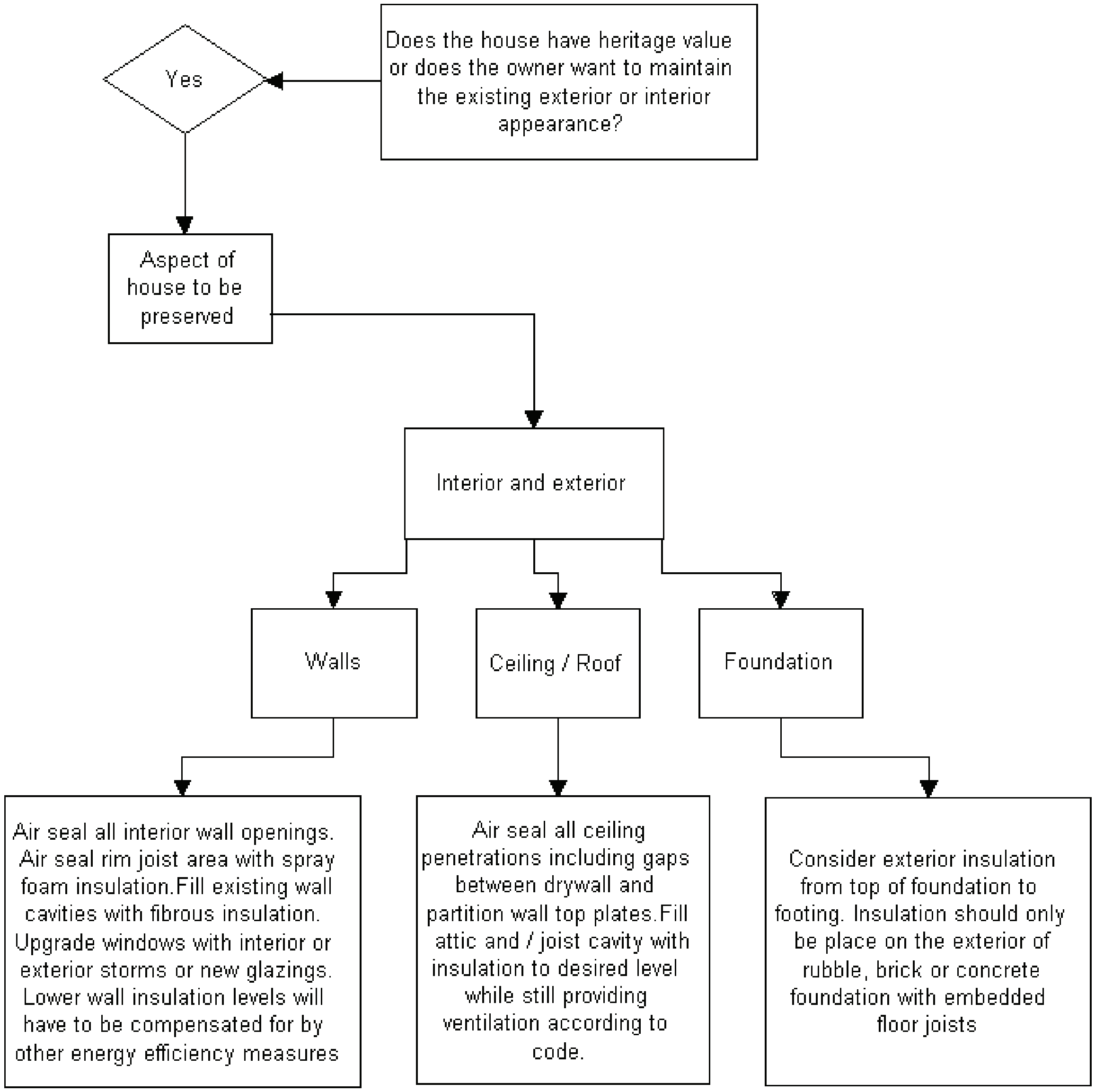
Preserve Exterior Wall Finish



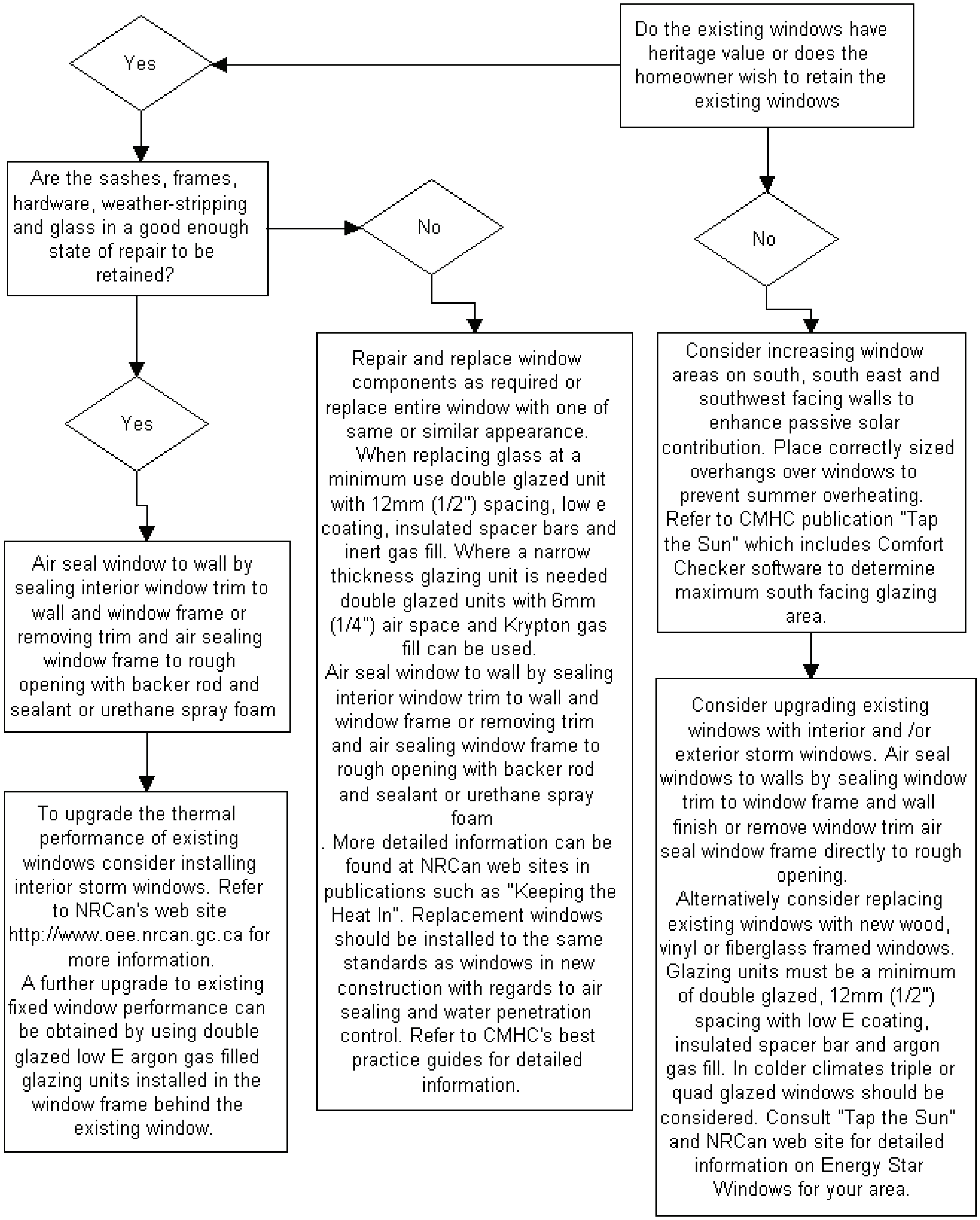
Preserve Interior Wall Finish



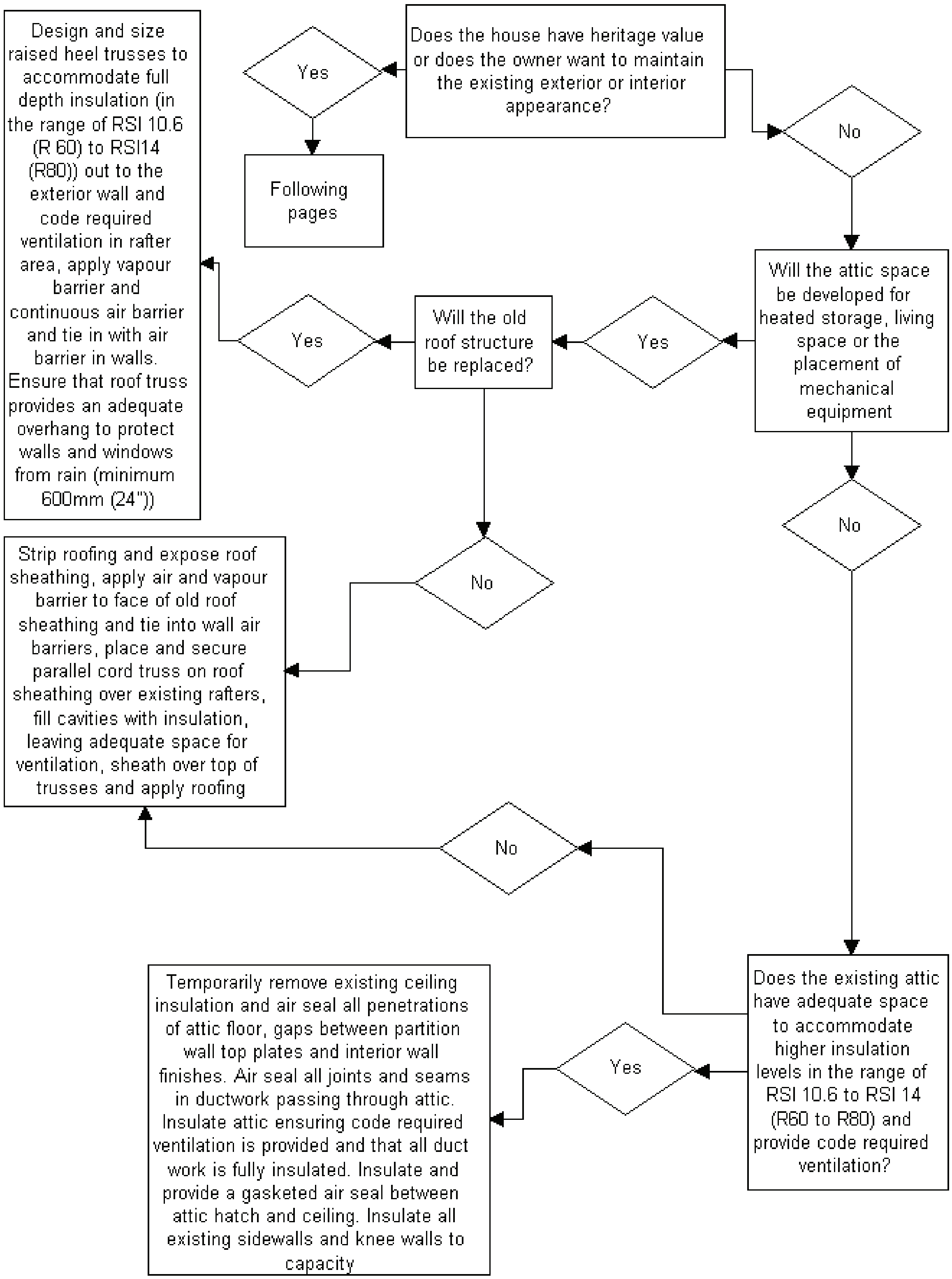
Preserve Interior and Exterior Wall Finish



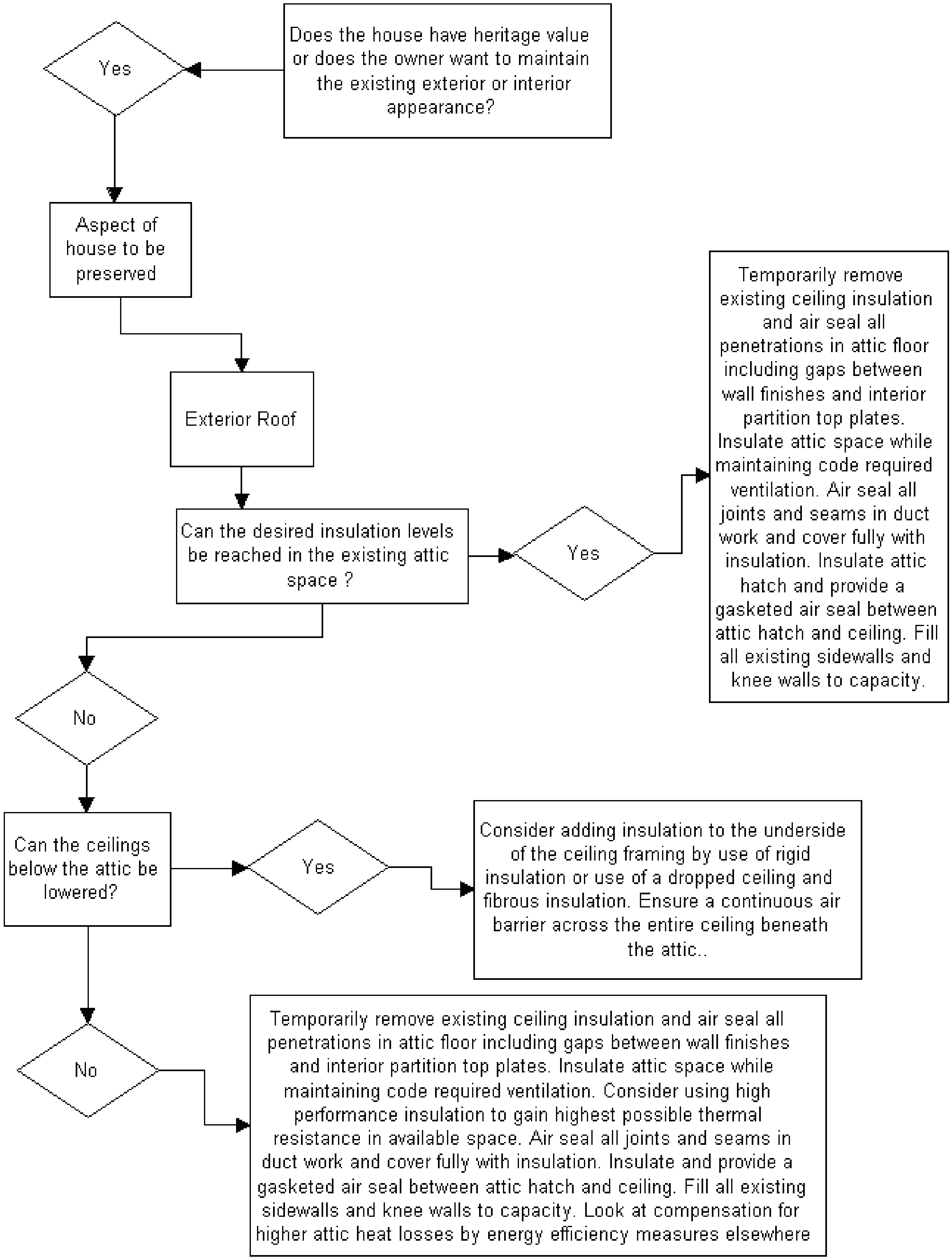
Windows


Do the existing windows have heritage value or does the homeowner wish to retain the existing windows
Yes
No
Are the sashes, frames, hardware, weather-stripping and glass in a good enough state of repair to be retained?
No
Yes
Air seal window to wall by sealing interior window trim to wall and window frame or removing trim and air sealing window frame to rough opening with backer rod and sealant or urethane spray foam
To upgrade the thermal performance of existing windows consider installing interior storm windows. Refer to NRCan's web site http://www.oee.nrcan.gc.ca for more information.
A further upgrade to existing fixed window performance can be obtained by using double glazed low E argon gas filled glazing units installed in the window frame behind the existing window.
Repair and replace window components as required or replace entire window with one of same or similar appearance. When replacing glass at a minimum use double glazed unit with 12mm (1/2") spacing, low e coating, insulated spacer bars and inert gas fill. Where a narrow thickness glazing unit is needed double glazed units with 6mm (1/4") air space and Krypton gas fill can be used.
Air seal window to wall by sealing interior window trim to wall and window frame or removing trim and air sealing window frame to rough opening with backer rod and sealant or urethane spray foam
. More detailed information can be found at NRCan web sites in publications such as "Keeping the Heat In". Replacement windows should be installed to the same standards as windows in new construction with regards to air sealing and water penetration control. Refer to CMHC's best practice guides for detailed information.
Consider increasing window areas on south, south east and southwest facing walls to enhance passive solar contribution. Place correctly sized overhangs over windows to prevent summer overheating. Refer to CMHC publication "Tap the Sun" which includes Comfort Checker software to determine maximum south facing glazing area.
Consider upgrading existing windows with interior and /or exterior storm windows. Air seal windows to walls by sealing window trim to window frame and wall finish or remove window trim air seal window frame directly to rough opening.
Alternatively consider replacing existing windows with new wood, vinyl or fiberglass framed windows. Glazing units must be a minimum of double glazed, 12mm (1/2") spacing with low E coating, insulated spacer bar and argon gas fill. In colder climates triple or quad glazed windows should be considered. Consult "Tap the Sun" and NRCan web site for detailed information on Energy Star Windows for your area.

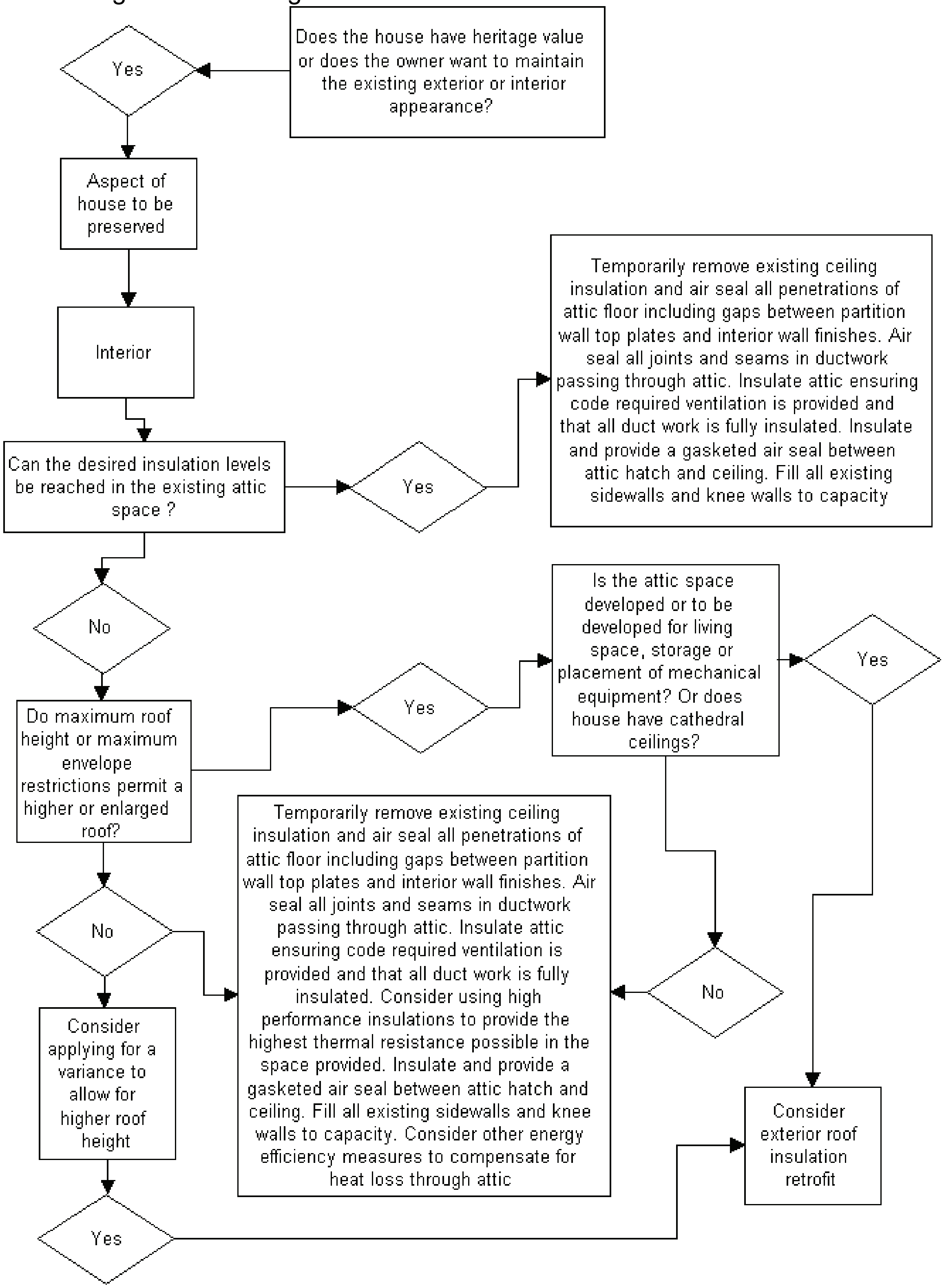
Roofs


Does the house have heritage value or does the owner want to maintain the existing exterior or interior appearance?
Yes
Following pages
No
Will the attic space be developed for heated storage, living space or the placement of mechanical equipment
Yes
Will the old roof structure be replaced?
Yes
Design and size raised heel trusses to accommodate full depth insulation (in the range of RSI 10.6 (R 60) to RSI14 (R80)) out to the exterior wall and code required ventilation in rafter area, apply vapour barrier and continuous air barrier and tie in with air barrier in walls. Ensure that roof truss provides an adequate overhang to protect walls and windows from rain (minimum 600mm (24"))
No
Strip roofing and expose roof sheathing, apply air and vapour barrier to face of old roof sheathing and tie into wall air barriers, place and secure parallel cord truss on roof sheathing over existing rafters, fill cavities with insulation, leaving adequate space for ventilation, sheath over top of trusses and apply roofing
No
Does the existing attic have adequate space to accommodate higher insulation levels in the range of RSI 10.6 to RSI 14 (R60 to R80) and provide code required ventilation?
No
Yes
Temporarily remove existing ceiling insulation and air seal all penetrations of attic floor, gaps between partition wall top plates and interior wall finishes. Air seal all joints and seams in ductwork passing through attic. Insulate attic ensuring code required ventilation is provided and that all duct work is fully insulated. Insulate and provide a gasketed air seal between attic hatch and ceiling. Insulate all existing sidewalls and knee walls to capacity

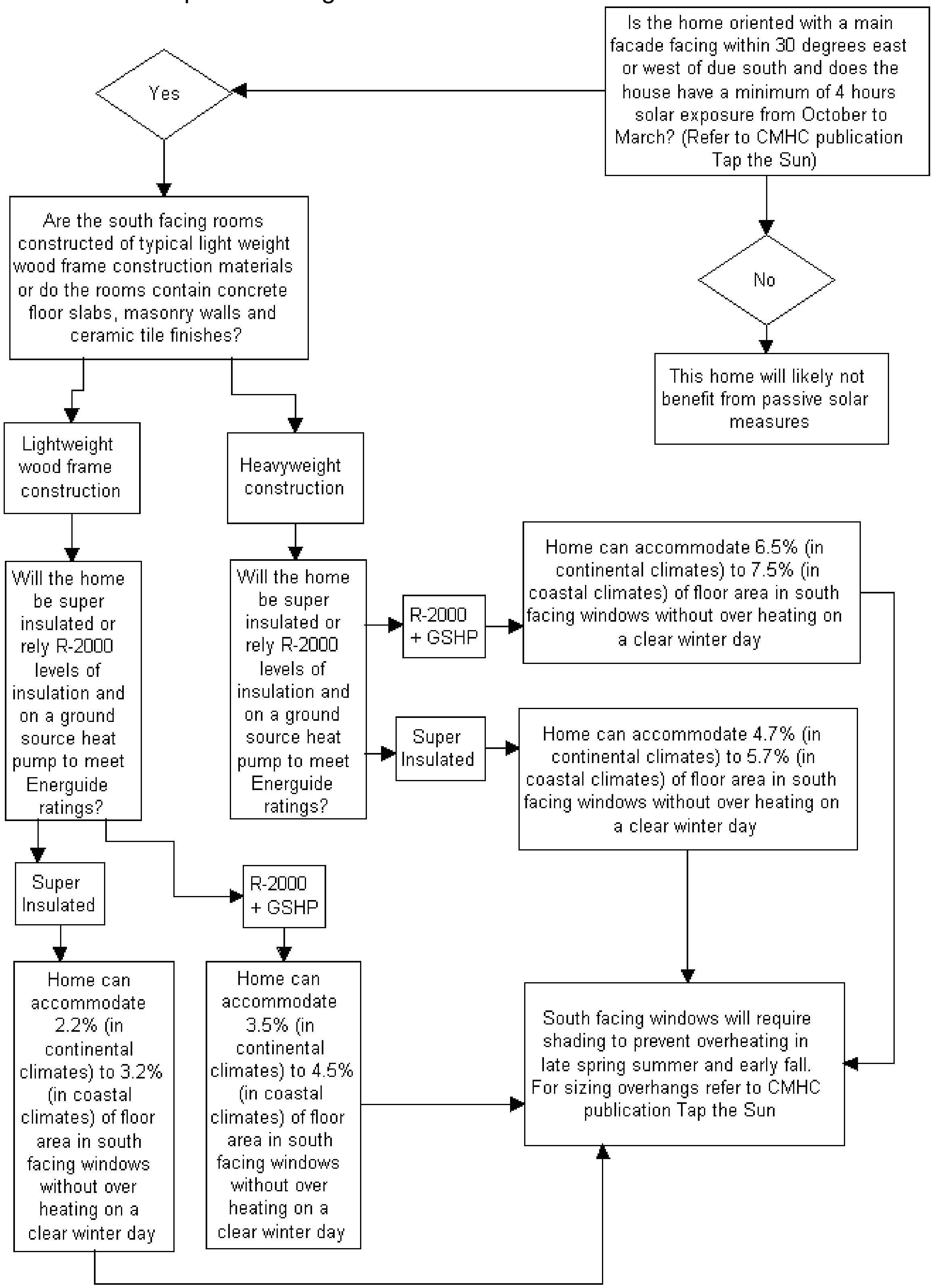
Preserve Exterior Roof Form and Finish



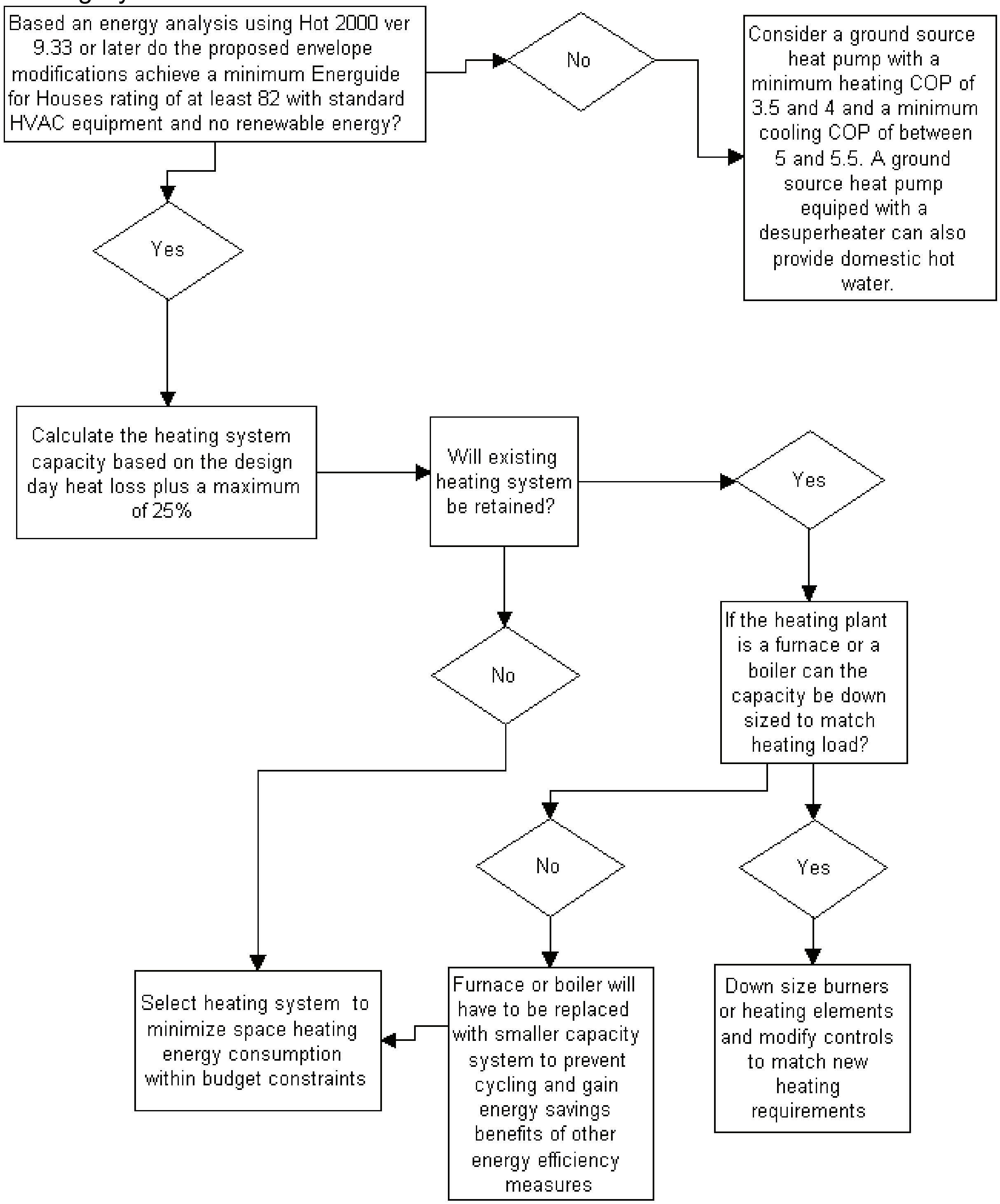
Preserving Interior Ceiling Finish



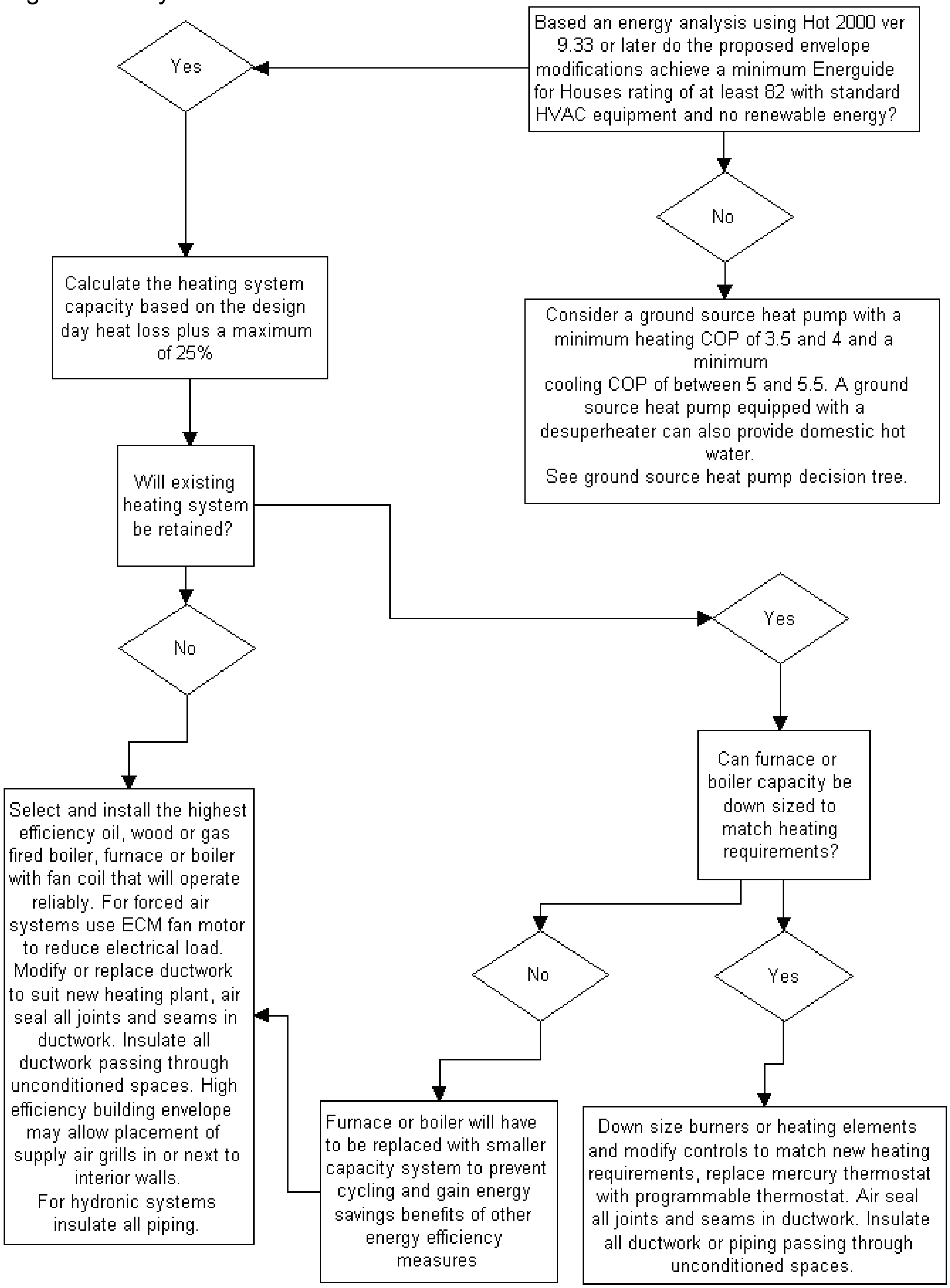
Passive Solar Space Heating



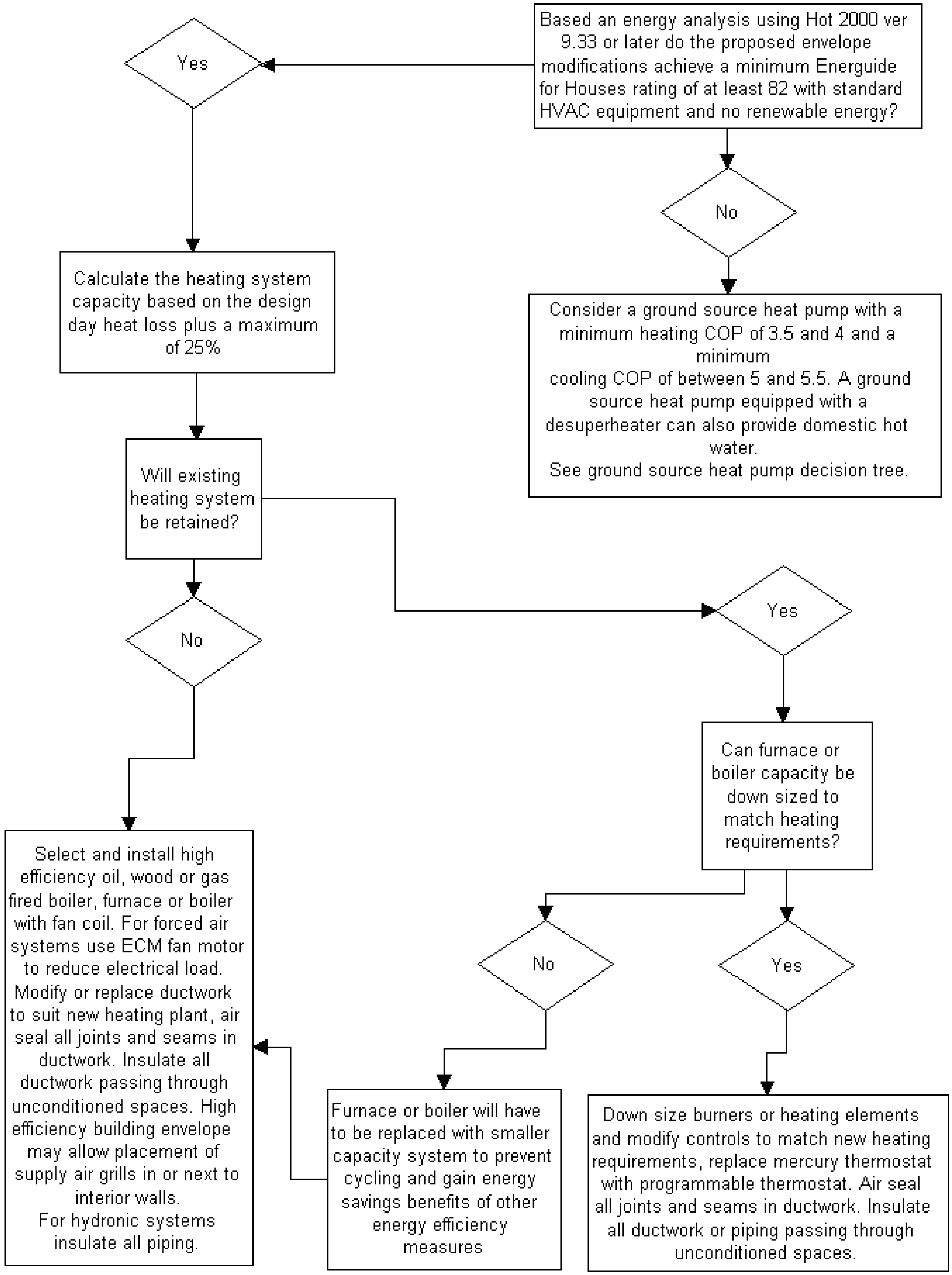
Heating Systems



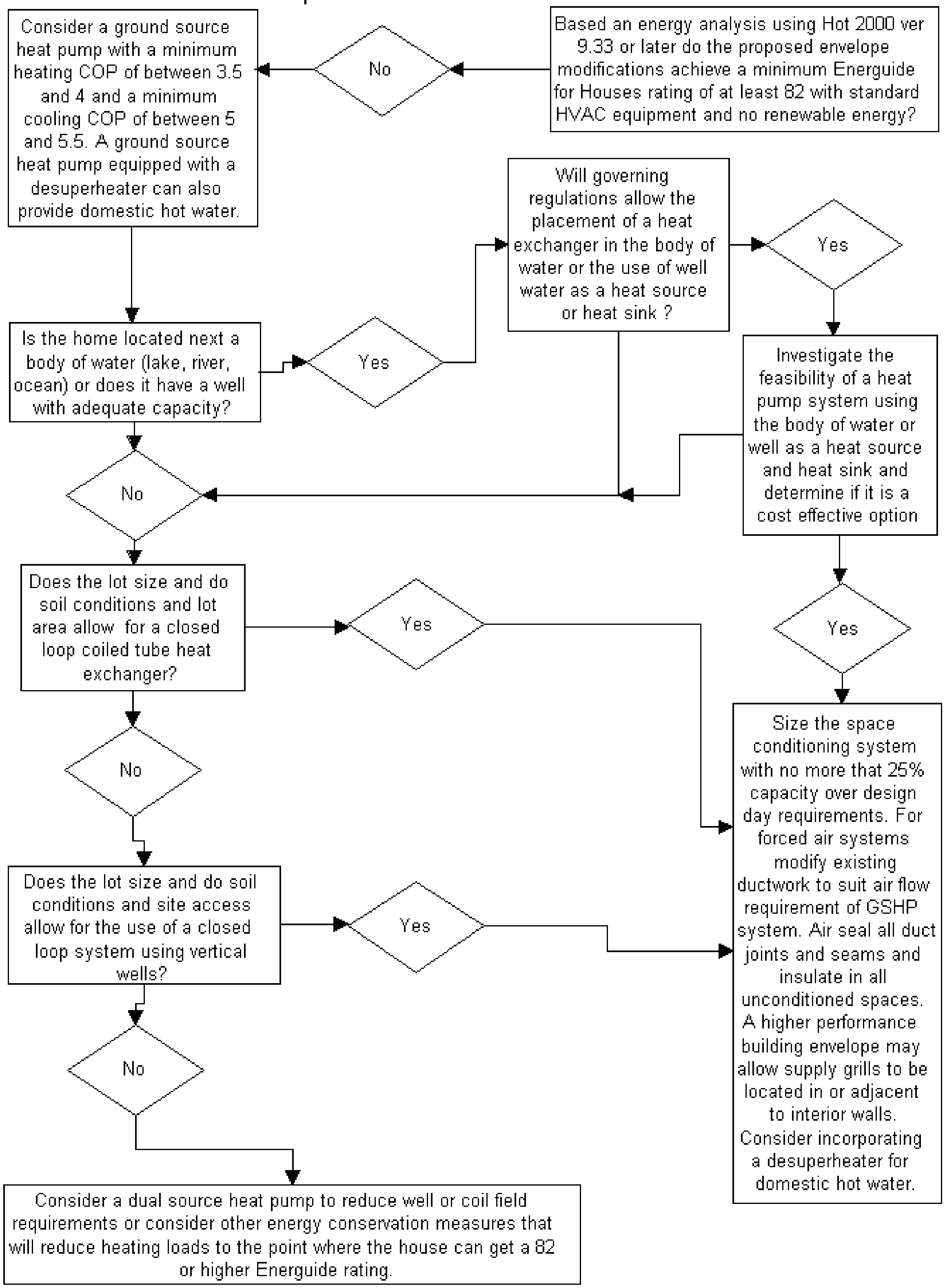
High Efficiency Furnace or Boiler



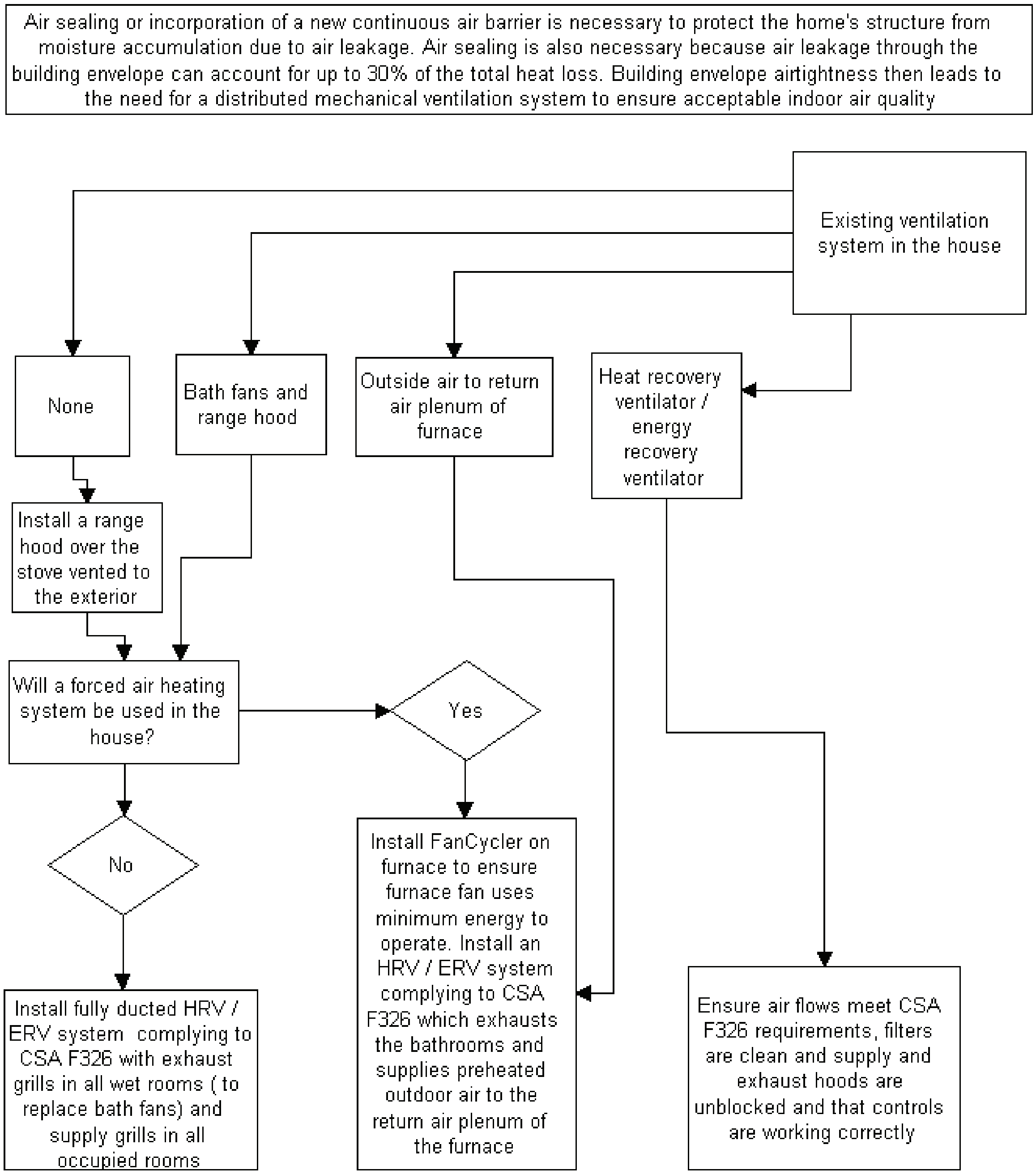
Gas Furnace


Based an energy analysis using Hot 2000 ver 9.33 or later do the proposed envelope modifications achieve a minimum Energuide for Houses rating of at least 82 with standard HVAC equipment and no renewable energy?
Yes
No
Consider a ground source heat pump with a minimum heating COP of 3.5 and 4 and a minimum cooling COP of between 5 and 5.5. A ground source heat pump equipped with a desuperheater can also provide domestic hot water.
See ground source heat pump decision tree.
Calculate the heating system capacity based on the design day heat loss plus a maximum of 25%
Will existing heating system be retained?
No
Yes
Can furnace or boiler capacity be down sized to match heating requirements?
Select and install high efficiency oil, wood or gas fired boiler, furnace or boiler with fan coil. For forced air systems use ECM fan motor to reduce electrical load. Modify or replace ductwork to suit new heating plant, air seal all joints and seams in ductwork. Insulate all ductwork passing through unconditioned spaces. High efficiency building envelope may allow placement of supply air grills in or next to interior walls.
For hydronic systems insulate all piping.
No
Yes
Furnace or boiler will have to be replaced with smaller capacity system to prevent cycling and gain energy savings benefits of other energy efficiency measures
Down size burners or heating elements and modify controls to match new heating requirements, replace mercury thermostat with programmable thermostat. Air seal all joints and seams in ductwork. Insulate all ductwork or piping passing through unconditioned spaces.

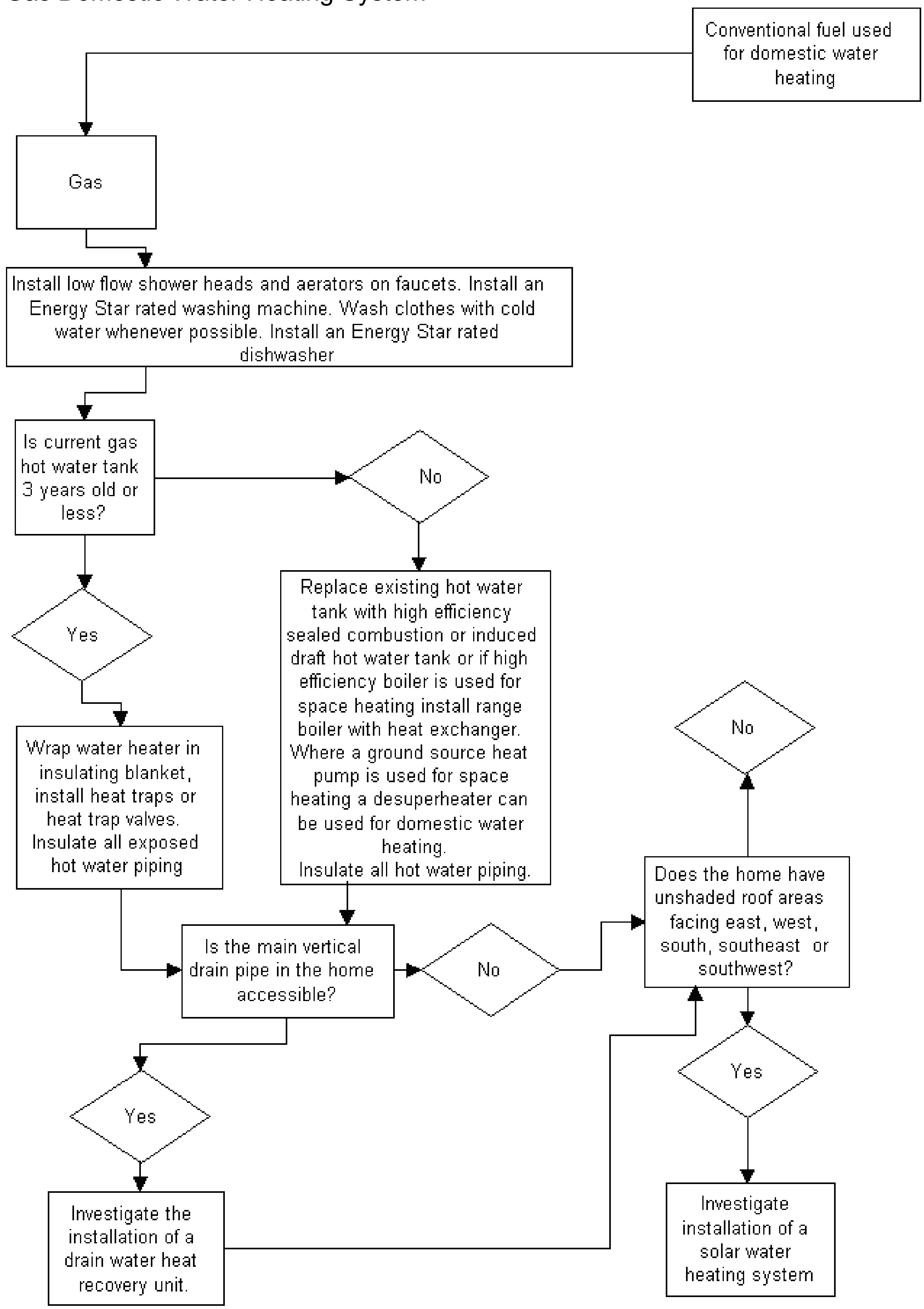
Ground Source Heat Pump



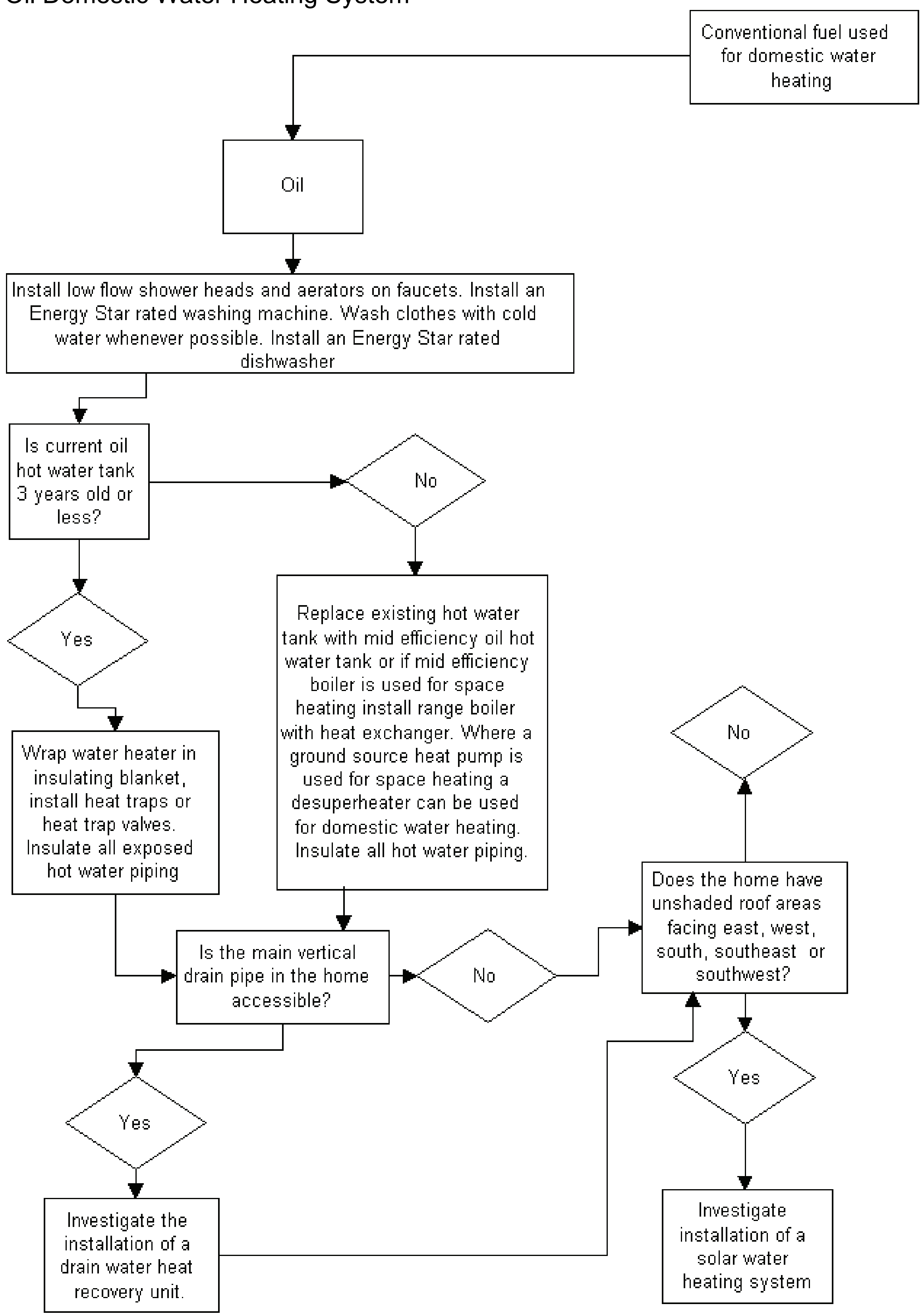
Ventilation



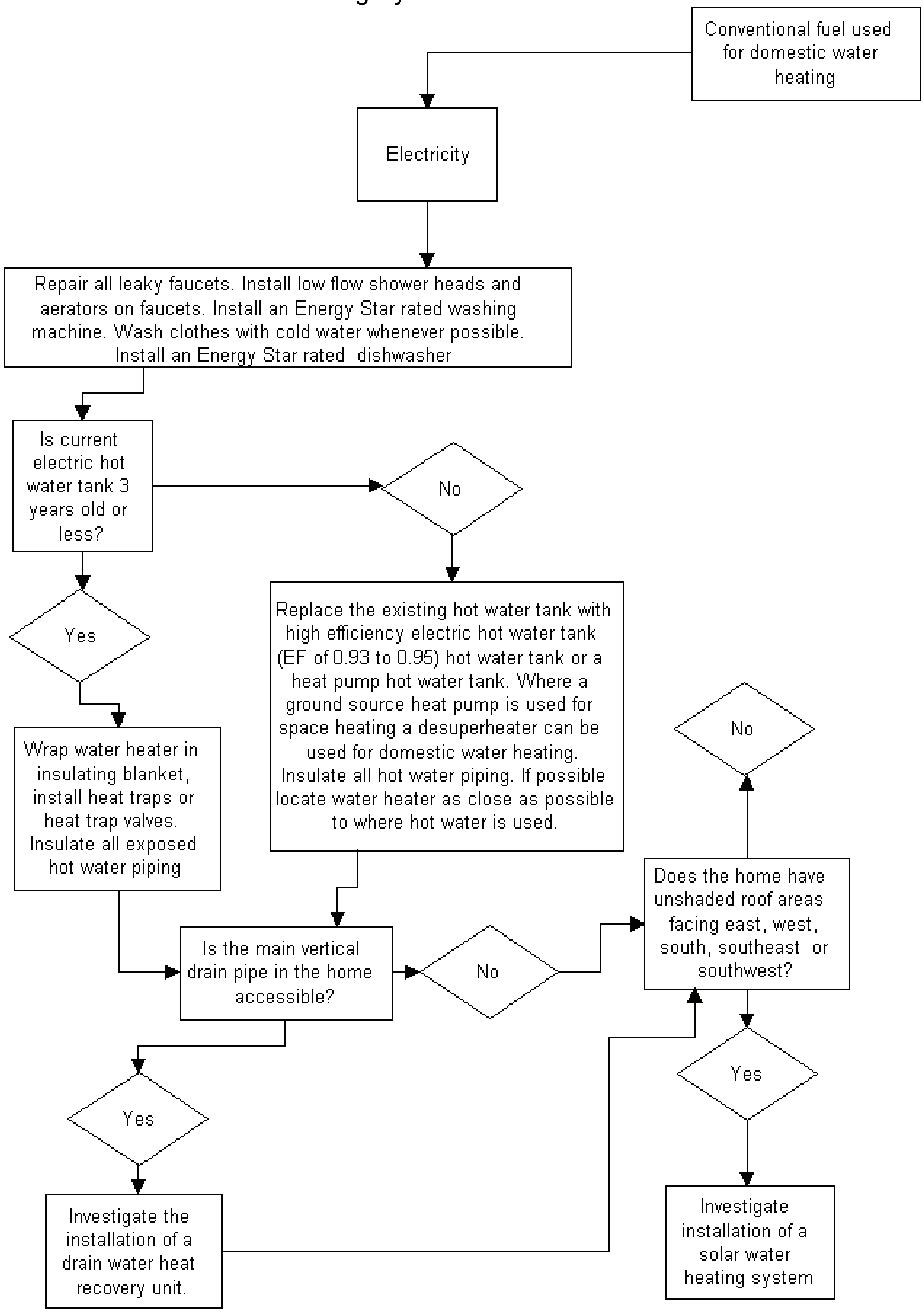
Gas Domestic Water Heating System



Oil Domestic Water Heating System



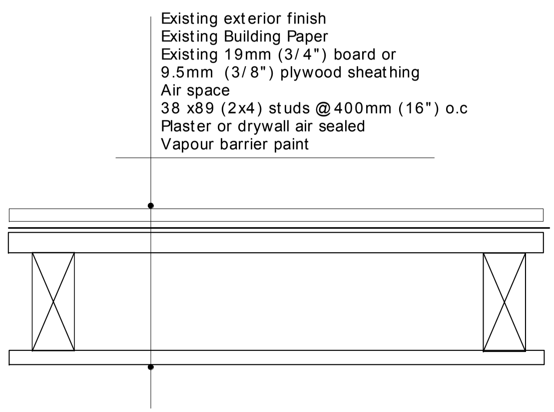
Electric Domestic Water Heating System



Appendix B: Building Envelope Upgrade Options

The first section of this appendix shows a selected series of upgrade assemblies for walls and ceilings with precise insulation value analysis. The second section is a list of potential assemblies, with only nominal insulation figures given.

Wall: Base Case Uninsulated

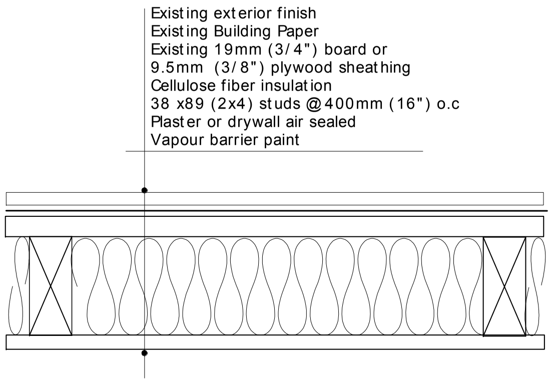


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2K)/W$	Btu/ h ft^2F	$W/(m^2K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Air space					1.00	0.18	1.00	5.68
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**3.98**	**0.70**	**0.25**	**1.43**
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**7.53**	**1.33**	**0.13**	**0.75**

Percentage of wall in cavity	81.00%
Percentage of wall in framing	19.00%

Total composite values			
R	**RSI**	**U**	**USI**
4.37	**0.77**	**0.23**	**1.30**

Wall: Base Case Insulated

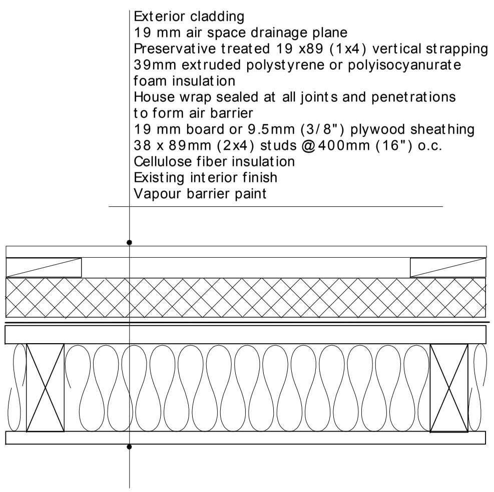


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2 K)/W$	Btu/ h·ft^{2}F	W/(m^2K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**15.58**	**2.74**	**0.06**	**0.36**
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**7.53**	**1.33**	**0.13**	**0.75**

Percentage of wall in cavity 81.00%
Percentage of wall in framing 19.00%

Total composite values			
R	**RSI**	**U**	**USI**
12.94	**2.28**	**0.08**	**0.44**

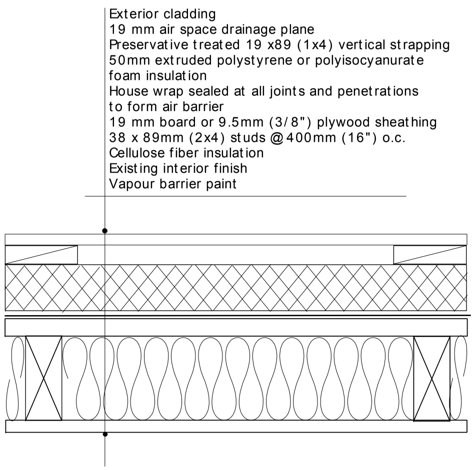
Wall: Base case insulated with 38mm (1.5") foam board (isocyanurate or XPS)



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^2F	$W/(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
38mm (1 1/2") foam board	1.5	38	5	0.034	7.50	1.32	0.13	0.76
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**23.88**	**4.20**	**0.04**	**0.24**
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical stapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
38mm (1 1/2") foam board	1.5	38	5	0.034	7.50	1.32	0.13	0.76
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			**Totals**	**15.80**	**2.78**	**0.06**	**0.36**
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
21.97	**3.87**	**0.05**	**0.26**

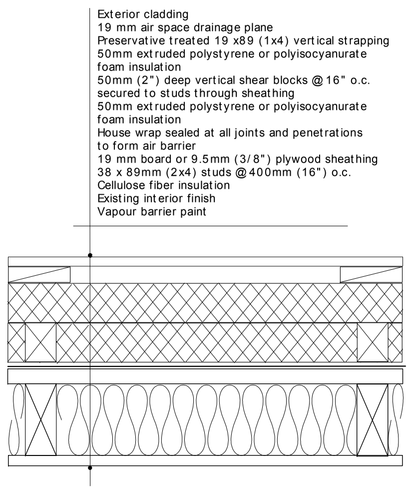
Wall: Base case insulated with 50 mm (2") foam board (isocyanurate or XPS)



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm		h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^2F	$W/(m^2 K)$	$W/(m^2 K)$
Exterior Air Film				0.20	0.04	5.00	28.39	
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
50mm (2") foam board	2	38	5	0.034	10.00	1.76	0.10	0.57
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	**26.21**	**9.61**	**0.04**	**0.10**
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical stapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
50mm (2") foam board	2	38	5	0.034	10.00	1.76	0.10	0.57
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			**Totals**	**18.30**	**3.22**	**0.05**	**0.31**
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
24.42	**7.19**	**0.04**	**0.14**

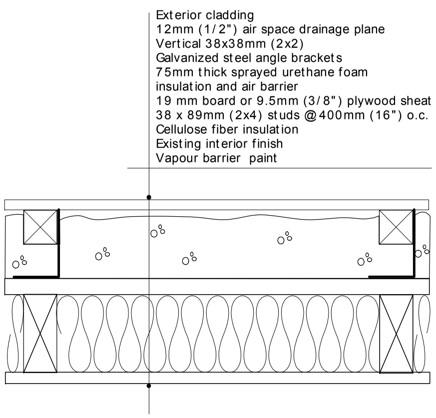
Wall: Base case insulated with 100mm (4") foam board (isocyanurate or XPS)



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	(m^2·K)/W	Btu/ h·ft^{2}F	W/(m^2K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
100mm (4") foam board	4	38	5	0.034	20.00	3.52	0.05	0.28
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	36.38	6.41	0.03	0.16
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical strapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
50mm (2") foam board	2	38	5	0.034	10.00	1.76	0.10	0.57
38mm vertical shear block	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	20.58	3.62	0.05	0.28
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
32.17	**5.67**	**0.03**	**0.18**

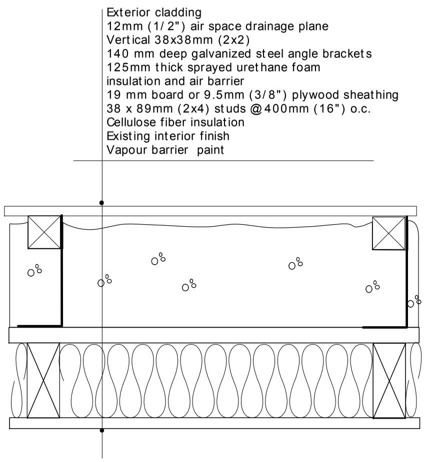
Wall: Base case insulated with 76mm (3") of closed cell urethane spray foam insulation



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^{2}F	$W/(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
75mm (3") closed cell spray urethane foam	3	75	6	0.041	18.00	3.17	0.06	0.32
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	34.38	6.05	0.03	0.17
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
38mm vertical shear block	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
67.5mm (2.5") closed cell spray urethane foam	2.5	67.5	6	0.041	15.00	2.64	0.07	0.38
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	24.60	4.33	0.04	0.23
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
32.20	**5.67**	**0.03**	**0.18**

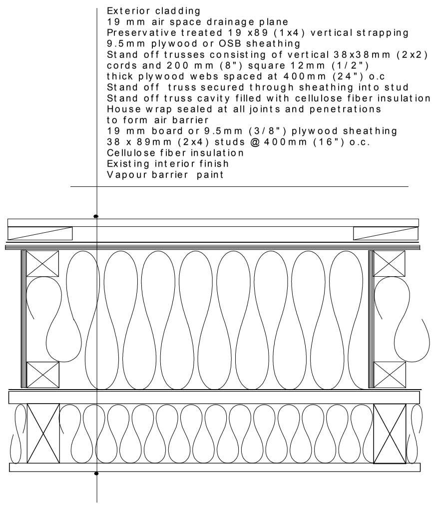
Wall: Base case insulated with 127mm (5") of closed cell urethane spray foam insulation



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^{2}F	W/$(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
125mm (5") closed cell spray urethane foam	5	140	6	0.034	30.00	5.28	0.03	0.19
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	46.38	8.17	0.02	0.12
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
38mm vertical shear block	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
114 mm (4.5") closed cell spray urethane foam	4.5	114	6	0.041	27.00	4.76	0.04	0.21
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	36.60	6.45	0.03	0.16
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
44.36	**7.81**	**0.02**	**0.13**

Wall: Base case insulated with 203 mm (8") deep stand off trusses filled with cellulose



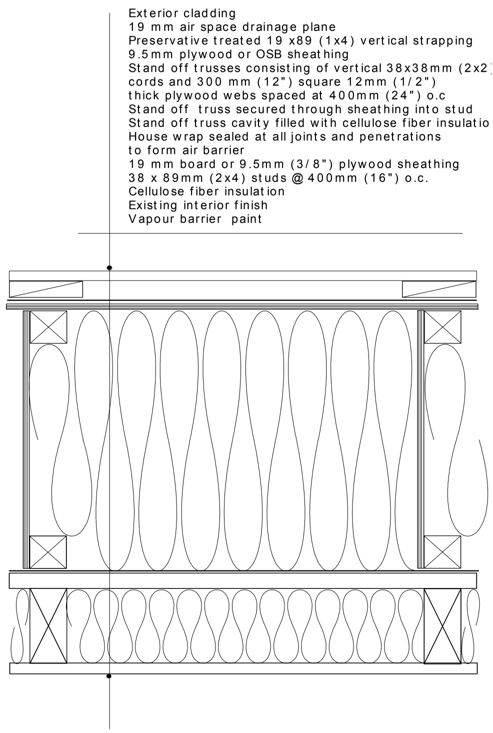
Percentage of wall in cavity		83.00%
Percentage of wall in framing		17.00%

Total composite values

R	RSI	U	USI
42.51	**7.48**	**0.02**	**0.13**

	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^2F	$W/(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
Building paper					0.20	0.03	5.00	33.33
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
Cellulose fiber insulation	8	200	3.6	0.025	28.80	5.07	0.03	0.20
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	45.86	8.07	0.02	0.12
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical strapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
Cellulose fiber insulation	5	125	3.6	0.025	18.00	3.17	0.06	0.32
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	31.34	5.52	0.03	0.18

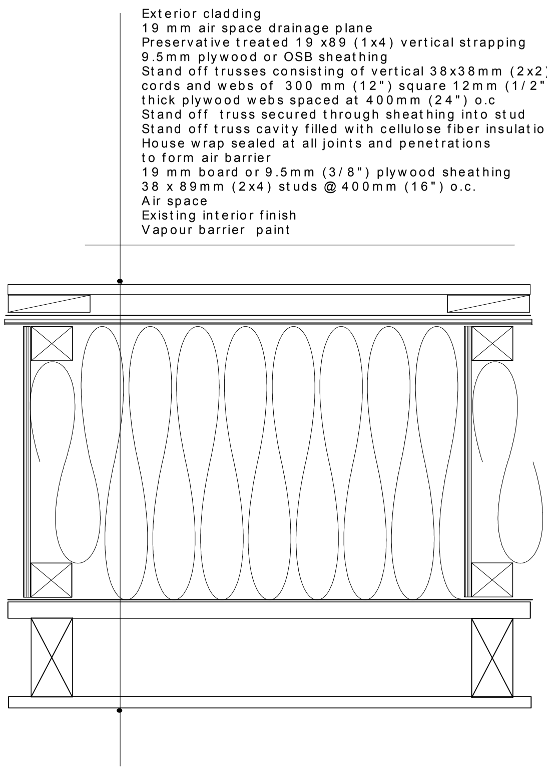
Wall: Base case insulated with 305 mm (12") deep stand off trusses filled with cellulose



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^{2}F	$W/(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
Building paper					0.20	0.03	5.00	33.33
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
Cellulose fiber insulation	12	300	3.6	0.025	43.20	7.61	0.02	0.13
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	60.26	10.61	0.02	0.09
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical strapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
Cellulose fiber insulation	9	228	3.6	0.025	32.40	5.71	0.03	0.18
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	45.74	8.06	0.02	0.12
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
57.18	**10.07**	**0.02**	**0.10**

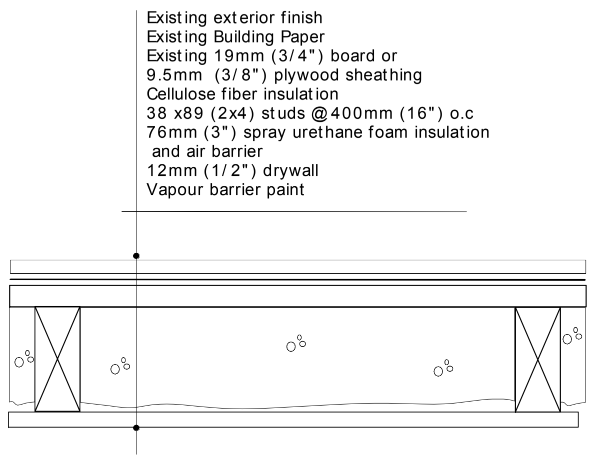
Wall: Base case uninsulated with 305 mm (12") deep stand off trusses filled with cellulose insulation



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2K)/W$	Btu/ h ft^2F	$W/(m^2K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Air Space	0.75	19			1.00	0.18	1.00	5.68
Building paper					0.20	0.03	5.00	33.33
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
Cellulose fiber insulation	12	300	3.6	0.025	43.20	7.61	0.02	0.13
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Air space	3.5	89			1.00	0.18	1.00	5.68
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	48.66	8.57	0.02	0.12
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
19 x 89 (1x4) vertical strapping	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
9.5mm (3/8") plywood sheathing	0.375	9.5	1.3	0.0087	0.49	0.09	2.05	11.65
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
Cellulose fiber insulation	9	228	3.6	0.025	32.40	5.71	0.03	0.18
38mm truss cord	1.75	38	1.3	0.0087	2.28	0.40	0.44	2.50
House wrap	0.006	0.15			0.00	0.00		
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	45.74	8.06	0.02	0.12
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
48.14	**8.47**	**0.02**	**0.12**

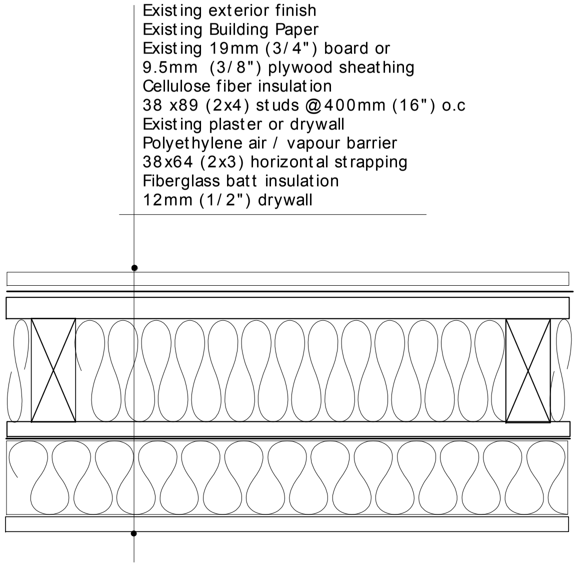
Wall: Base case insulated with closed cell spray urethane foam



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2 \cdot K)/W$	Btu/ h·ft^{2}F	W/(m^2·K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Spray in place closed cell polyurethane	3	89	6	0.041	18.00	3.17	0.06	0.32
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	20.98	3.69	0.05	0.27
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	81.00%			Totals	7.53	1.33	0.13	0.75
Percentage of wall in framing	19.00%							

Total composite values			
R	**RSI**	**U**	**USI**
15.66	**2.76**	**0.06**	**0.36**

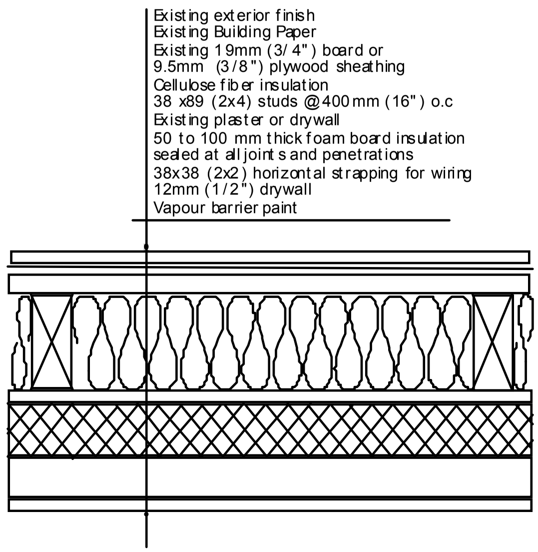
Wall: Base case insulated cavity with 50 x 76 mm (2 x 3) interior cross strapping filled with fiber glass insulation



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2 \cdot K)/W$	Btu/ h·ft^{2}F	$W/(m^2 \cdot K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Fiberglass insulation	2.5	63.5	3.2	0.022	8.00	1.41	0.13	0.71
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	23.68	4.17	0.04	0.24
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
63.5mm (2 1/2") cross strapping	2.5	63.5	1.3	0.0087	3.25	0.57	0.31	1.75
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	81.00%			Totals	10.88	1.92	0.09	0.52
Percentage of wall in framing	19.00%							

Total composite values			
R	**RSI**	**U**	**USI**
19.35	**3.41**	**0.05**	**0.29**

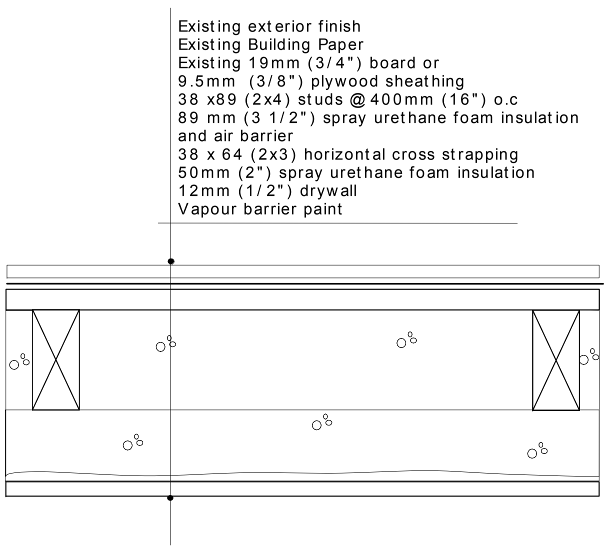
Wall: Base case uninsulated with 50 mm (2") foam board and 50 x 50 mm (2 x 2) cross strapping wiring chase



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h.ft2F/Btu	(m2.K)/W	Btu/ h.ft2F	W/(m2.K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster					0.10	0.02	10.00	56.78
Isocyanurate foam board	2	63.5	5	0.022	10.00	1.76	0.10	0.57
Air space					1.00	0.18	1.00	5.68
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	26.68	4.70	0.04	0.21
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Isocyanurate foam board	2.5	63.5	5	0.0087	12.50	2.20	0.08	0.45
63.5mm (2 1/2") cross strapping	2.5	63.5	1.3	0.0087	3.25	0.57	0.31	1.75
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	81.00%			Totals	23.38	4.12	0.04	0.24
Percentage of wall in framing	19.00%							

Total composite values			
R	RSI	U	USI
25.98	4.58	0.04	0.22

Wall: Base case insulated cavity with 50 x 75 mm (2 x 3) interior cross strapping filled with closed cell polyurethane

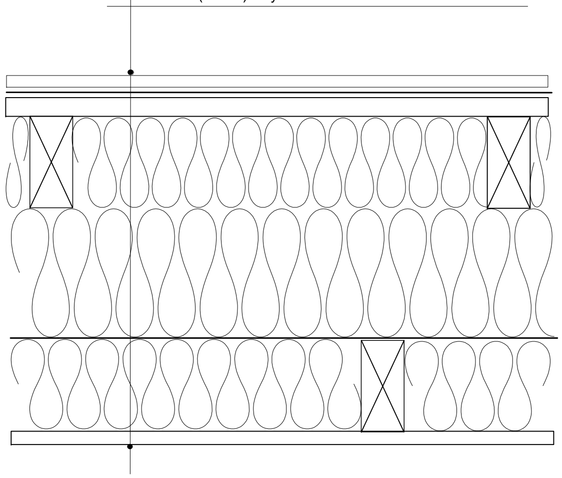


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^{2}F	W/(m^2K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Spray in place closed cell polyurethane	3.5	89	6	0.041	21.00	3.70	0.05	0.27
Spray in place closed cell polyurethane	2	50	6	0.041	12.00	2.11	0.08	0.47
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	35.98	6.34	0.03	0.16
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
63.5mm (2 1/2") cross strapping	2.5	63.5	1.3	0.0087	3.25	0.57	0.31	1.75
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	81.00%			Totals	10.78	1.90	0.09	0.53
Percentage of wall in framing	19.00%							

Total composite values			
R	**RSI**	**U**	**USI**
24.91	**4.39**	**0.04**	**0.23**

Wall: Original cavity + new interior framed wall 140 mm (5.5") stand off, batt insulation

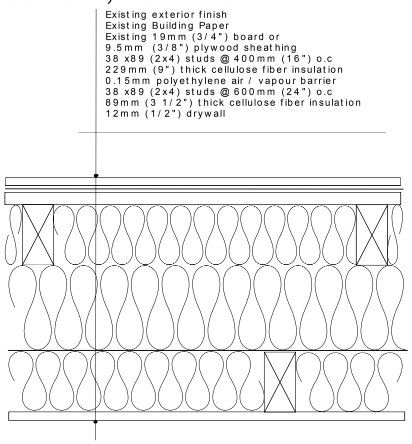
Existing exterior finish
Existing Building Paper
Existing 19mm (3/4") board or
9.5mm (3/8") plywood sheathing
38 x89 (2x4) studs @400mm (16") o.c
89mm (3 1/2") thick batt insulation
140mm (5 1/2") thick batt insulation laid horizontally
Polyethylene air / vapour barrier
38 x89 (2x4) studs @600mm (24") o.c
89mm (3 1/2") thick batt insulation
12mm (1/2") drywall



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	(m^2K)/W	Btu/ h ft^{2}F	W/(m^2K)
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Mineral wool fiber batt	3.5	89	3.5	0.024	12.25	2.16	0.08	0.46
Mineral wool fiber batt	5.5	140	3.5	0.024	19.25	3.39	0.05	0.29
Polyethylene air / vapour barrie	0.006	0.15	0	0	0.00	0.00		
Mineral wool fiber batt	3.5	89	3.5	0.024	12.25	2.16	0.08	0.46
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	46.73	8.23	0.02	0.12
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Mineral wool fiber batt	5.5	140	3.5	0.024	19.25	3.39	0.05	0.29
Polyethylene air / vapour barrie	0.006	0.15	0	0	0.00	0.00		
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
Percentage of wall in cavity	83.00%			Totals	31.33	5.52	0.03	0.18
Percentage of wall in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
43.12	**7.59**	**0.02**	**0.13**

Wall: Original cavity + new interior framed wall 140 mm (5.5") standoff, cellulose



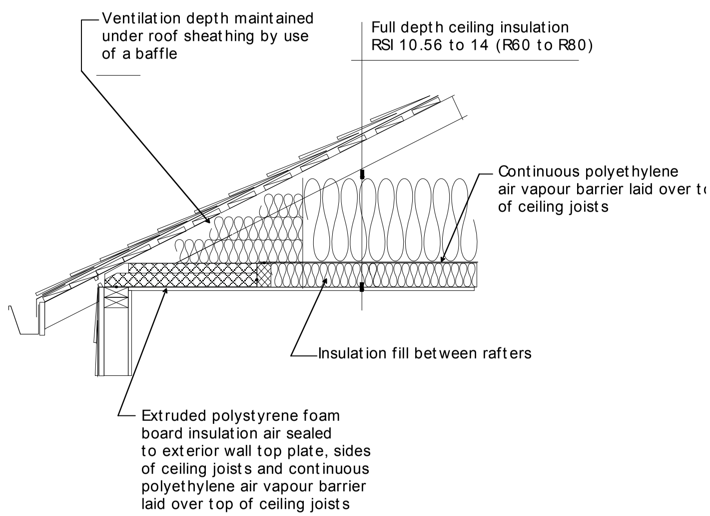
Percentage of wall in cavity 83.00%
Percentage of wall in framing 17.00%

Total composite values

R	**RSI**	**U**	**USI**
43.93	**7.74**	**0.02**	**0.13**

	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h ft2F/Btu	$(m^2 K)/W$	Btu/ h ft^{2}F	$W/(m^2 K)$
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Cellulose fiber insulation	3.5	89	3.6	0.024	12.60	2.22	0.08	0.45
Cellulose fiber insulation	5.5	140	3.6	0.024	19.80	3.49	0.05	0.29
Polyethylene air / vapour barrie	0.006	0.15	0	0	0.00	0.00		
Cellulose fiber insulation	3.5	89	3.5	0.024	12.25	2.16	0.08	0.46
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	47.63	8.39	0.02	0.12
Stud Section								
Exterior Air Film					0.20	0.04	5.00	28.39
Cladding (1/2" x 8" bevel)					0.80	0.14	1.25	7.10
Building Paper					0.20	0.04	5.00	28.39
19mm (3/4") board sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Cellulose fiber insulation	5.5	140	3.6	0.024	19.80	3.49	0.05	0.29
Polyethylene air / vapour barrie	0.006	0.15	0	0	0.00	0.00		
89mm (3 1/2") thick stud	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster					0.10	0.02	10.00	56.78
Interior Air Film					0.70	0.12	1.43	8.11
				Totals	31.88	5.61	0.03	0.18

Roof: Existing attic upgrade

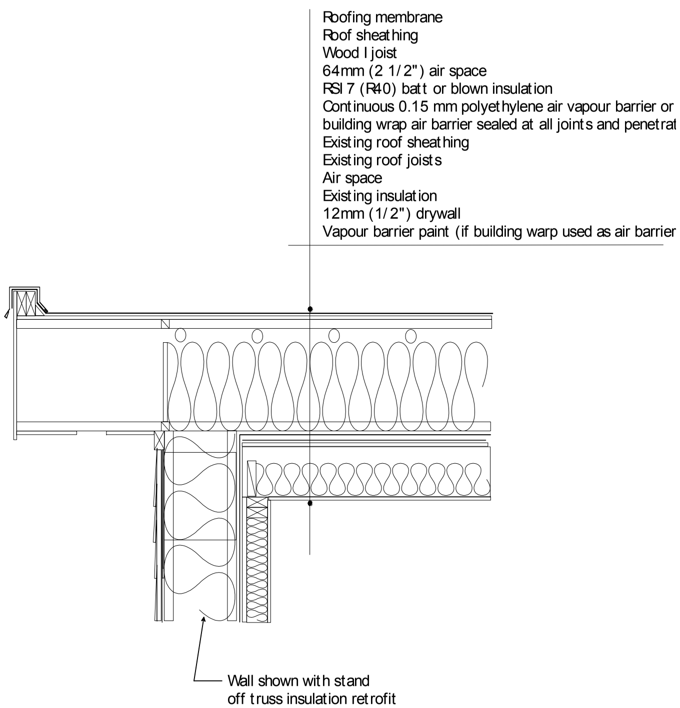


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2K)/W$	Btu/ h·ft²F	$W/(m^2K)$
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Air Space					0.90	0.15	1.11	6.67
Batt or blown insulation above top of joists	12	300	3.6	0.025	43.20	7.61	0.02	0.13
Batt or blown insulation between joists	3.5	89	3.6	0.025	12.60	2.22	0.08	0.45
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
				Totals	59.48	10.47	0.02	0.10
Framed section								
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
38 x 89 (2x4) rafters	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Air Space					0.90	0.15	1.11	6.67
Batt or blown insulation above top of joists	12	300	3.6	0.025	43.20	7.61	0.02	0.13
38 x 89 (2x4) ceiling joists	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
Percentage of roof in cavity	83.00%			Totals	55.98	9.85	0.02	0.10
Percentage of roof in framing	17.00%							

Attic space at perimeter 74mm (29")

Total composite values			
R	**RSI**	**U**	**USI**
58.85	**10.36**	**0.02**	**0.10**

Roof: Wood I Joists Placed over Existing Roof Structure

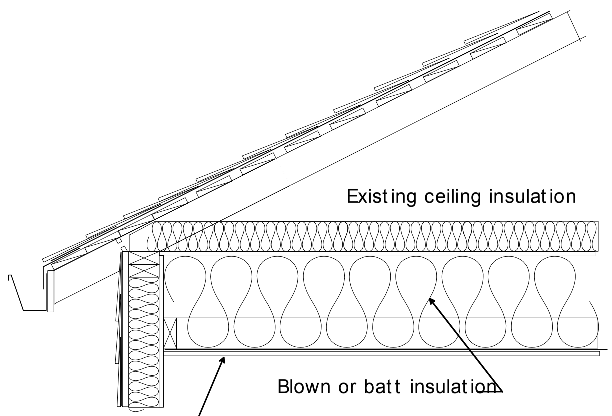


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2 K)/W$	Btu/ h·ft^{2}F	W/(m^2K)
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
Air Space					0.60	0.11	1.67	9.46
Batt or blown insulation between I joists	12	300	3.6	0.025	43.20	7.61	0.02	0.13
Roof sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Air space					0.90	0.16	1.11	6.31
Batt or blown existing attic insulation	5.5	89	3.6	0.025	19.80	3.49	0.05	0.29
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
				Totals	67.76	11.94	0.01	0.08
Framed section								
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
I joists	16	300	1.3	0.0087	20.80	3.66	0.05	0.27
Roof sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
38 x 89 (2x4) rafters	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Air space					0.90	0.16	1.11	6.31
Batt or blown existing attic insulation	2.5	89	3.6	0.025	9.00	1.59	0.11	0.63
38 x 89 (2x4) ceiling joists	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
Percentage of roof in cavity	83.00%			Totals	43.06	7.59	0.02	0.13
Percentage of roof in framing	17.00%							

Total composite values

R	RSI	U	USI
61.74	**0.62**	**0.02**	**1.61**

Roof: Attic Roof with Dropped Ceiling

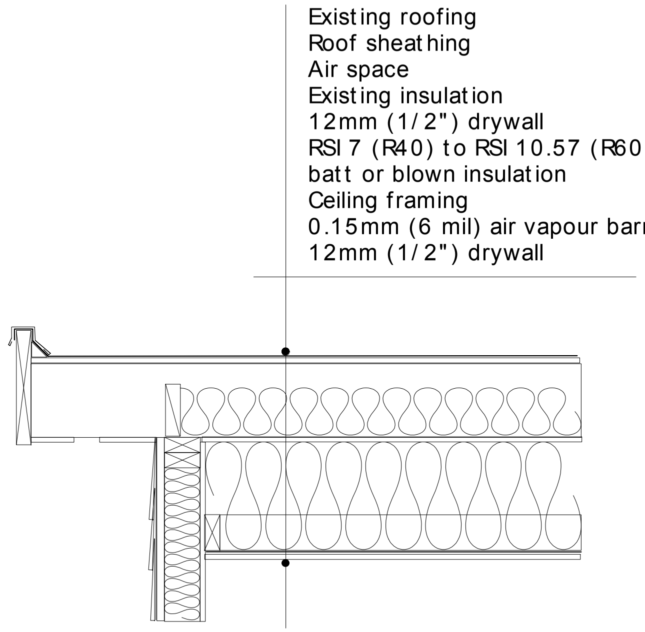


	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	(m^2·K)/W	Btu/ h·ft^{2}F	W/(m^2K)
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
Air Space					0.90	0.15	1.11	6.67
Existing batt or blown insulation	5.5	300	3.6	0.025	19.80	3.49	0.05	0.29
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Batt or blown insulation	12	89	3.6	0.025	43.20	7.61	0.02	0.13
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
				Totals	66.78	11.76	0.01	0.09
Framed section								
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.75	19	1.3	0.0087	0.98	0.17	1.03	5.82
38 x 89 (2x4) rafters	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Air Space					0.90	0.15	1.11	6.67
Batt or blown insulation above top of joists	2	300	3.6	0.025	7.20	1.27	0.14	0.79
38 x 89 (2x4) ceiling joists	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Insulation over top of ceiling joists	8.5	216	3.6	0.025	30.60	5.39	0.03	0.19
38 x 89 (2x4) ceiling joists	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Interior Air Film					0.60	0.11	1.67	9.09
Percentage of roof in cavity	83.00%			Totals	55.13	9.70	0.02	0.10
Percentage of roof in framing	17.00%							

Total composite values

R	RSI	U	USI
64.46	**11.35**	**0.02**	**0.09**

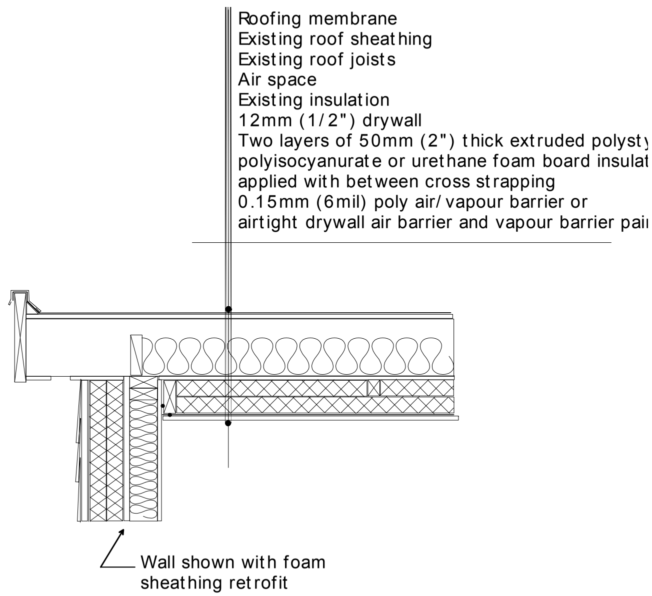
Roof: Flat Roof with Dropped Ceiling



	Thickness		R /in	RSI/mm	R	RSI	U	USI
Cavity section	in	mm			h·ft2F/Btu	$(m^2K)/W$	Btu/ h·ft^{2}F	$W/(m^2K)$
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
Air Space					0.90	0.15	1.11	6.67
Existing batt or blown insulation	5.5	300	3.6	0.025	19.80	3.49	0.05	0.29
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Batt or blown insulation	12	89	3.6	0.025	43.20	7.61	0.02	0.13
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
				Totals	66.29	11.67	0.02	0.09
Framed section								
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
38 x 184 (2x8) joists	7.25	184	1.3	0.0087	9.43	1.66	0.11	0.60
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Insulation over top of ceiling joists	8.5	216	3.6	0.025	30.60	5.39	0.03	0.19
38 x 89 (2x4) ceiling joists	3.5	89	1.3	0.0087	4.55	0.80	0.22	1.25
Interior Air Film					0.60	0.11	1.67	9.09
Percentage of roof in cavity	83.00%			Totals	46.86	8.26	0.02	0.12
Percentage of roof in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
61.92	**10.90**	**0.02**	**0.09**

Roof : Flat Roof with Shallow Dropped Ceiling



Cavity section	Thickness in	Thickness mm	R /in	RSI/mm	R h·ft2F/Btu	RSI (m^2·K)/W	U Btu/ h·ft^{2}F	USI W/(m^2K)
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
Air Space					0.90	0.15	1.11	6.67
Existing batt or blown insulation	5.5	300	3.6	0.025	19.80	3.49	0.05	0.29
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Foam board insulation	4	100	5	0.025	20.00	3.52	0.05	0.28
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Interior Air Film					0.60	0.11	1.67	9.09
				Totals	43.09	7.58	0.02	0.13
Framed section								
Exterior Air Film					0.60	0.11	1.67	9.46
Roofing					0.50	0.09	2.00	11.36
Sheathing	0.375	19	1.3	0.0087	0.49	0.09	2.05	11.65
38 x 184 (2x8) joists	7.25	184	1.3	0.0087	9.43	1.66	0.11	0.60
12 mm plaster	0.5	12	0.2	0.0014	0.10	0.02	10.00	56.78
Insulation over top of ceiling joists	2	216	5	0.025	10.00	1.76	0.10	0.57
38 x 38 (2x2) ceiling strapping	1.75	44.5	1.3	0.0087	2.28	0.40	0.44	2.50
Interior Air Film					0.60	0.11	1.67	9.09
Percentage of roof in cavity	83.00%			Totals	23.99	4.23	0.04	0.24
Percentage of roof in framing	17.00%							

Total composite values			
R	**RSI**	**U**	**USI**
37.95	**6.68**	**0.03**	**0.15**

Other Suggested Assemblies for Meeting Upgrade Targets	
	Assumptions about insulating materials quoted: blown cellulose = RSI 0.0253/mm (R 3.5/in), f/g batts= RSI 0.0220 (R 3.2/in) polyisocyanurate board = RSI 0.0420/mm (R 6 to R 7/in), polyurethane foam = RSI 0.0420/mm (R 6 to R 7/in), SIPS panel insulation quoted from product mfr. All given values are nominal and do not include remainder of wall assembly.

Ceilings	
1	Add f/g batts or blown cell w/eave ventilation to attic, high R-value rigid board at eaves to improve thermal weak spot.
2	For sloped clg, create 'hot roof': completely fill rafter cavity w/densepack blown cell, add rigid insulation to interior clg 25 to 50 mm (1"- 2") of various product to reach target. Thicker boards than indicated = challenge w/fasteners and installation of sheathing or interior finish.
3	If re-roofing sloped ceiling, add rigid to exterior to target, see note w/interior application.
4	Use spray polyurethane foam insulation in roof rafter cavity (RSI 6/R 33 for 38*140 (2x6) rafter, RSI 8.3/R 45 for 38*190 (2x8) rafter). High R-value, but question @ 'green' product -- no capacity for dismantle/reuse of product or framing.
Walls	
	Where some walls will never make the upgrade target (ie, heritage solid brick home), other options need to be explored, such as going to a high-efficiency GSHP and a Solar DHW system to compensate for energy use. This type of solution will also benefit from PV installation in getting closer to Net Zero, if there is little or no thermal resistance use in the house.
RSI 4.6 (R 26)	
1	fill 38*89 (2x4) exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell, add 50mm(2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to exterior or interior. Can be done when residing or when renovating interior.
	If not already insulated, fill 38*89 (2x4) exterior wall cavities w/RSI 2.1 (R12) densepack blown cell, add 100mm (4") SIPS panel to exterior RSI 2.8 (R16). Total insulation = RSI 4.93 (R28).
2	If not already insulated, fill 38*89 (2x4) exterior wall cavities w/RSI 2.1 (R12) densepack blown cell, strap off wall 2x3 and add 64mm (2.5") f/g w/RSI 1.4 (R8) to interior. Gives approximately RSI 3.5 (R20). Exterior = add 25mm (1") polyiso board under replacement siding
3	When residing 38*140 (2x6) exterior walls, ensure cavity is completely filled (RSI 3.5/R 20) with f/g batts or dense-pack blown cell, add 25mm (1") polyiso board (RSI 1.05-1.23/R 6 to R 7)
4	Brick veneer walls w/38*89 (2x4) cavity: same as option 1 RSI 4.2 (R 24) or 2 (without the exterior board installation) Gives RSI 3.87 (R 22)
5	Brick veneer walls w/38*140 (2x6) cavity: ensure cavity is completely filled (RSI 3.5/R 20) with f/g batts or dense-pack blown cell, add 25mm (1") polyiso board (RSI 1.05-1.23/R 6 to R 7) to interior
6	Solid brick walls from interior: add 50mm (2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to interior, or strap off wall 2x4 and add 64mm (3.5") blown-in polyurethane foam RSI 3.7 to 4.3 (R 21 to 24.5)
7	Solid brick walls from exterior: if brick is in need of repair or facelift, cover with 75mm (3") polyiso foam RSI 3.17 to 3.7 (R 18 to R 21) and finish with stucco (appropriate rainscreen/drainage plane required)

RSI 7/R 40	
1	From exterior of 38*89 (2x4) wall assembly: add 200mm (8") standoff 'truss' wall with RSI 4.9 (R28) densepack blown cell or 230mm (9") standoff 'truss' wall with RSI 4.9 (R 28) f/g batts to exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell. Can be done when residing.
2	From exterior of 38*89 (2x4) wall assembly: add 50mm (2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell. Add 50mm (2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to interior wall. Total insulation = RSI 6.3(R 36 to 38). Where 64mm (2.5") board is available, would be a better choice for exterior.
3	From exterior of 38*140 (2x6) wall assembly: add 50mm (2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to exterior wall cavities w/RSI 3.5 (R 20) densepack blown cell. Can be done when residing. Interior: strap off wall 2x3 and add 64mm (2.5") f/g w/RSI 1.4 (R 8). Total insulation = RSI 7 to7.4 (R 40 to 42).
4	From exterior of 38*140 (2x6) wall assembly: add 38mm (1.5") polyiso board RSI 1.58 to 1.85 (R 9 to 10.5) to exterior wall cavities w/RSI 3.5 (R 20) densepack blown cell. Can be done when residing. Interior: add 38mm (1.5") polyiso board RSI 1.6 to 1.9 (R 9 to 10.5). Total insulation = RSI 6.7 to7.2 (R 38 to 41).
5	Brick veneer walls w/38*89 (2x4) cavity: fill 38*89 (2x4) exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell, add 50mm(2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to exterior or interior. Can be done when residing or when renovating interior. If exterior needs facelift, add either 75mm (3") polyiso foam RSI 3.17 to 3.7 (R 18 to R21) and finish with stucco (appropriate rainscreen/drainage plane required), or 100mm (4") SIPS panel to exterior RSI 2.8 (R 16). Total insulation with exterior facelift = RSI 7 to 7.4 (R 40 to R 41)
6	Brick veneer walls w/38*140 (2x6) cavity: ensure cavity is completely filled (RSI 3.5/R 20) with f/g batts or dense-pack blown cell, strap out interior 38*89 (2x4) wall and fill w/spray on polyurethane foam RSI 3.7 to 4.3 (R 21to 24.5). Total insulation= RSI 7.22 to 7.84 (R 41 to 44.5)
7	Solid brick walls: add 50mm (2") polyiso board RSI 2.1 to 2.5 (R 12 to 14) to interior, or strap off wall 2x4 and add 64mm (3.5") blown-in polyurethane foam RSI 3.7 to 4.3 (R 21 to 24.5). If brick is in need of repair or facelift, cover with 75mm (3") polyiso foam RSI 3.17 to 3.7 (R 18 to R21) and finish with stucco (appropriate rainscreen/drainage plane required. Total insulation = RSI 5.63 to 8.01 (R 32 to 45.5)

RSI 10.6/R 60	
1	From exterior of 38*89 (2x4) wall assembly: add 64mm (1.5") polyiso board sheathing RSI 1.59 to 1.85 (R 9 to 10.5) to 200mm (12") standoff 'truss' wall with RSI 7.4 (R42) densepack blown cell or RSI 6.7 (R 38) f/g batts to exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell. Insulation total = RSI 10.4 to 11.36 (R 59 to 64.5) Can be done when residing. If using densepack cell in the standoff wall, the sheathing thickness could be reduced to 25mm (1").
2	From exterior of 38*140 (2x6) wall assembly: add to 200mm (12") standoff 'truss' wall with RSI 7.4 (R 42) densepack blown cell or RSI 6.7 (R 38) f/g batts to exterior wall exterior wall cavities w/ RSI 3.5 (R 20) densepack blown cell. Can be done when residing. Total insulation = RSI 10.2 to10.9 (R 58 to 62).
3	From exterior of 38*89 (2x4) wall assembly: standoff wall is reduced to 200mm (8") if standoff cavity is blown in polyurethane foam insulation at RSI 0.041/mm (R 6/inch) and stud wall cavity is filled to RSI 2.11 (R 12).
4	From exterior of 38*140 (2x6) wall assembly: standoff wall is reduced to 180mm (7") if standoff cavity is blown in polyurethane foam insulation at RSI 0.041/mm (R 6/inch) and stud wall cavity is filled to RSI 3.5 (R 20).
5	Brick veneer walls w/38*140 (2x6) cavity: ensure cavity is completely filled (RSI 3.5/R 20) with f/g batts or dense-pack blown cell, strap out interior 38*89 (2x4) wall and fill w/spray on polyurethane foam RSI 3.7 to 4.3 (R 21to 24.5). If brick is in need of repair or facelift, cover with 75mm (3") polyiso foam RSI 3.17 to 3.7 (R 18 to R21) and finish with stucco (appropriate rainscreen/drainage plane required. Alternately, a 100mm (4") SIPS panel can be used on exterior RSI 2.82 (R 16). Total insulation= RSI 10.04 to 11.53 (R 57 to 65.5).
6	Brick veneer walls from interior w/38*140 (2x6) cavity: strip of cavity existing insulation, strap out interior 38*89 (2x4) wall and fill 230mm (9') cavity w/spray on polyurethane foam RSI 3.7 to 4.3 (R 54 to 63).

RSI 14.4/R 80	
1	From exterior of 38*89 (2x4) wall assembly: add 50mm (2") polyiso board sheathing RSI 2.11 to 2.46 (R 12 to 14) to 200mm (16") standoff 'truss' wall with RSI 9.9 (R 56) densepack blown cell or RSI 9 (R 51.2) f/g batts to exterior wall cavities w/RSI 2.1 (R 12) densepack blown cell. Insulation total = RSI 13.24 to 14.44 (R 75.2 to 82) Can be done when re-siding.
2	From exterior of 38*140 (2x6) wall assembly: add 64mm (1.5") polyiso board sheathing RSI 1.59 to 1.85 (R 9 to 10.5) to 200mm (16") standoff 'truss' wall with RSI 9.9 (R 56) densepack blown cell or RSI 9 (R 51.2) f/g batts to exterior wall cavities w/RSI 3.5 (R 20) densepack blown cell. Insulation total = RSI 14.1 to 15.23 (R8 0.2 to 86.5) Can be done when residing. If using densepack cell in the standoff wall, the sheathing thickness could be reduced to 25mm (1").
3	From exterior of 38*89 (2x4) wall. Standoff wall is reduced to 300mm (12") if standoff cavity is blown in polyurethane foam insulation at RSI 0.041/mm (R 6/inch) and stud wall cavity is filled to RSI 2.11 (R 12).
4	From exterior of 38*140 (2x6) wall. Standoff wall is reduced to 250mm (10") if standoff cavity is blown in polyurethane foam insulation at RSI 0.041/mm (R 6/inch) and stud wall cavity is filled to RSI 3.5 (R 20).
5	Brick veneer walls from interior w/38*140 (2x6) cavity: strip of cavity existing insulation, strap out interior 38*89 (2x4) wall and fill 230mm (9') cavity w/spray on polyurethane foam RSI 3.7 to 4.3 (R 54 to 63). If brick is in need of repair or facelift, cover with 75mm (3") polyiso foam RSI 3.17 to 3.7 (R 18 to R21) and finish with stucco (appropriate rainscreen/drainage plane required. Alternately, a 100mm (4") SIPS panel can be used on exterior RSI 2.82(R 16). Total insulation= RSI 12.33 to 14.79 (R 70 to 84).

Headers	
1	Air sealing techniques as per Keeping the Heat In (caulk baseboards, clg penetrations etc.)
2	When gutting a building, seal at rim joist and fill rim joist cavity to at least wall insulation levels
Exposed Floors	
1	Retrofit from exterior w/polyiso, use as exterior air/vapour barrier
2	Spray urethane foam into cavity and seal from ext with polyiso board to match wall insulation value. See note above at clgs
Basement Walls	
1	RSI 3.5 (R 26) stand-off interior wall if non-finished basement, keep any framing off conc. wall. 50mm(2") polyiso board (RSI 2.1/R 12) with 39x89 (2x4) stud wall (RSI 2.1/R 12). Gives RSI 4.2/R 24 nominal. 50mm (2") board is easier to find than 64mm (2.5") board, but the thicker board would be RSI 2.64(R 15), bringing the nominal insulation up to RSI 4.74(R 27).
2	Combination of exterior and interior insulation if non-finished basement, standoff wall above plus 50mm (2") polyiso RSI 2.11 to 2.5 (R 12 to 14). Total insulation = 6.69 to 7.04(R 38 to 40)
3	If finished basement (with or without interior insulation), add rigid board to exterior to maximum thickness possible to come close to or meet target).
Slab	
1	If unfinished, add RSI 1.4 to 1.8 (R 8 to 10) to slab, top w/finished floor
Doors	
	Unless heritage value is affected, replace w/insulated metal doors c/w magnetic weatherstripping.
Windows	
	Replace units w/appropriate high-performance window
	Add inserts to existing windows for permanent solution
	Add seasonal films for temporary solution

Appendix C: Base Case House Energy Use Figures

Overall Energy Reduction (GJ), without solar add-on systems

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehors e
PWW2A	space & dhw	202.3	225.8	215.7	129.4	235.1	227.2
	Appliance	33.8	34.1	34.0	31.5	34.7	34.1
	TOTAL	236.1	259.9	249.7	160.9	269.7	261.3
PWW2B	space & dhw			214.3	127.1	232.2	
	Appliance			34.0	31.5	34.6	
	TOTAL			248.3	158.7	266.8	
PWW2C	space & dhw			236.4	150.7		
	Appliance			34.3	31.5		
	TOTAL			270.7	182.2		
1.5STOREY	space & dhw	145.8	146.8	148.9	95.0	141.3	164.2
	Appliance	33.0	33.1	33.1	31.8	33.2	33.7
	TOTAL	178.8	179.9	182.1	126.8	174.6	197.9
2STOREY60	space & dhw	115.4	149.2	129.4	91.9	120.3	183.7
	Appliance	32.6	33.2	33.0	32.0	33.2	34.1
	TOTAL	148.0	182.4	162.4	123.9	153.5	217.8
2STOREY95	space & dhw	91.0	125.5	101.4	98.1	132.8	229.2
	Appliance	32.9	35.8	33.4	32.4	33.2	34.2
	TOTAL	123.9	161.3	134.7	130.5	166.0	263.4
BUNG60	space & dhw	154.0	132.9	117.8	85.6	128.5	143.7
	Appliance	33.1	33.1	32.8	32.1	33.0	33.6
	TOTAL	187.2	166.0	150.6	117.7	161.5	177.3
BUNG95	space & dhw	60.6	76.9	65.0	61.6	67.8	129.4
	Appliance	32.4	32.7	32.9	32.3	32.9	33.4
	TOTAL	93.0	109.6	97.9	93.9	100.6	162.8
SPLITLEVEL	space & dhw	125.0	160.7	138.6	101.5	121.4	177.0
	Appliance	32.7	33.4	33.1	33.6	33.4	34.3
	TOTAL	157.7	194.1	171.7	135.1	154.8	211.3
SPLITENTRY	space & dhw	106.7	143.9	117.9	83.5	108.2	158.8
	Appliance	32.5	33.1	32.8	33.2	32.9	33.7
	TOTAL	139.2	177.0	150.7	116.7	141.1	192.4
UP/DOWN	space & dhw	116.1	158.3	142.4	111.8	152.9	137.8
	Appliance	32.9	33.8	33.4	33.7	33.6	33.5
	TOTAL	149.0	192.1	175.8	145.4	186.5	171.3
ROWHOUSE	space & dhw	92.1	125.4	114.0	90.1	124.5	
	Appliance	32.5	33.3	33.0	33.2	33.1	
	TOTAL	124.6	158.6	147.0	123.4	157.6	

Appendix D: Upgrade Case Results

EGH ratings (without baseload or hot water use reductions)

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	EGHBASE EGHUPGRADE	44.0 87.0	51.0 84.0	45.0 83.0	62.0 87.0	47.0 88 (GSHP)	54.0 90.0
PWW2B	EGHBASE EGHUPGRADE			45.0 83.0	63.0 87.0	48.0 83.0	
PWW2C	EGHBASE EGHUPGRADE			40.0 85 (GSHP)	57.0 85 (GSHP)		
1.5STOREY	EGHBASE EGHUPGRADE	55.0 83.0	64.0 87.0	58.0 83.0	69.0 87.0	64.0 84.0	66.0 84.0
2STOREY60	EGHBASE EGHUPGRADE	67.0 87.0	69.0 85.0	67.0 86.0	73.0 88.0	70.0 85.0	69.0 91.0
2STOREY95	EGHBASE EGHUPGRADE	73.0 84.0	74.0 88.0	73.0 85.0	73.0 89.0	71.0 85.0	65.0 91.0
BUNG60	EGHBASE EGHUPGRADE	53.0 86.0	67.0 86.0	65.0 85.0	71.0 88.0	67.0 84.0	69.0 82.0
BUNG95	EGHBASE EGHUPGRADE	77.0 86.0	77.0 87.0	78.0 85.0	77.0 88.0	77.0 85.0	72.0 85.0
SPLITLEVEL	EGHBASE EGHUPGRADE	61.0 83.0	62.0 84.0	61.0 83.0	68.0 87.0	66.0 82.0	65.0 81.0
SPLITENTRY	EGHBASE EGHUPGRADE	66.0 85.0	66.0 86.0	66.0 85.0	72.0 88.0	72.0 84.0	70.0 84.0
UP/DOWN	EGHBASE EGHUPGRADE	64.0 83.0	63.0 84.0	66.0 81.0	60.0 87.0	65.0 81.0	62.0 83.0
ROWHOUSE	EGHBASE EGHUPGRADE	69.0 85.0	68.0 86.0	66.0 82.0	70.0 88.0	67.0 83.0	

EGH Rating, with Solar Domestic Hot Water (south facing)*

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	ENERGY LOAD	40.6	54.7	55.1	36.5	29.1	88.6
	SDHW SOUTH	6.5	9.9	8.3	8.2	8.2	7.7
	TOTAL (MJ)	34.1	44.8	46.8	28.4	20.9	80.9
	EGH*	88.6	85.8	84.4	88.9	93.2	73.7
PWW2B	ENERGY LOAD			51.1	36.2	61.6	
	SDHW SOUTH			8.4	8.2	8.2	
	TOTAL (MJ)	0.0	0.0	42.7	28.0	53.3	0.0
	EGH*			85.7	89.1	82.7	
PWW2C	ENERGY LOAD			39.5	41.3		
	SDHW SOUTH			8.4	8.2		
	TOTAL (MJ)	0.0	0.0	31.1	33.0	0.0	0.0
	EGH*			89.6	87.1		
1.5STOREY	ENERGY LOAD	49.6	41.4	48.5	32.8	49.4	69.7
	SDHW SOUTH	6.6	10.1	8.5	8.2	8.3	7.9
	TOTAL (MJ)	43.0	31.3	40.0	24.6	41.1	61.8
	EGH*	85.6	90.1	86.6	90.4	86.6	81.2
2STOREY60	ENERGY LOAD	38.2	41.4	44.5	35.4	55.2	91.3
	SDHW SOUTH	6.1	8.8	7.8	7.6	7.7	6.9
	TOTAL (MJ)	32.1	32.6	36.7	27.9	47.5	84.4
	EGH*	89.3	89.7	87.8	89.1	84.6	74.3
2STOREY95	ENERGY LOAD	48.7	49.3	45.4	31.6	60.0	87.7
	SDHW SOUTH	6.1	8.8	7.8	7.7	7.7	6.9
	TOTAL (MJ)	42.5	40.4	37.5	24.0	52.3	80.8
	EGH*	85.8	87.2	87.5	90.6	83.0	75.4
BUNG60	ENERGY LOAD	36.6	44.5	41.4	27.8	48.9	83.3
	SDHW SOUTH	6.1	8.8	7.8	7.6	7.7	6.9
	TOTAL (MJ)	30.5	35.7	33.6	20.2	41.2	76.4
	EGH*	89.8	88.7	88.8	92.1	86.6	76.8
BUNG95	ENERGY LOAD	21.0	38.7	38.5	36.9	44.4	67.4
	SDHW SOUTH	6.1	8.8	7.8	7.7	7.7	6.9
	TOTAL (MJ)	14.9	29.9	30.7	29.3	36.7	60.5
	EGH*	95.0	90.5	89.8	88.6	88.1	81.6
SPLITLEVEL	ENERGY LOAD	42.9	57.0	50.1	30.8	61.2	88.2
	SDHW SOUTH	6.1	8.8	7.8	7.6	7.7	6.9
	TOTAL (MJ)	36.8	48.2	42.3	23.2	53.4	81.3
	EGH*	87.7	84.7	85.9	90.9	82.6	75.3
SPLITENTRY	ENERGY LOAD	36.1	46.7	42.4	27.6	51.6	72.9
	SDHW SOUTH	6.1	8.8	7.8	7.6	7.7	6.9
	TOTAL (MJ)	30.0	37.8	34.6	20.0	43.8	66.0
	EGH*	90.0	88.0	88.4	92.2	85.8	79.9
UP/DOWN	ENERGY LOAD	44.7	55.7	60.0	31.3	63.7	54.0
	SDHW SOUTH	6.3	9.4	8.1	7.9	8.0	7.2
	TOTAL (MJ)	38.4	46.4	51.9	23.4	55.7	46.8
	EGH*	87.2	85.3	82.7	90.8	81.9	85.8
ROWHOUSE	ENERGY LOAD	36.3	45.9	51.2	27.5	53.4	
	SDHW SOUTH	6.5	9.7	8.3	8.1	8.2	
	TOTAL (MJ)	29.9	36.1	42.9	19.4	45.2	
	EGH*	90.0	88.5	85.7	92.4	85.3	

EGH* Rating, with Solar Domestic Hot Water (east or west facing)

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	ENERGY LOAD	40.6	54.7	55.1	36.5	29.1	88.6
	SDHW E-W	5.5	7.4	6.8	6.5	6.6	6.2
	TOTAL (MJ)	35.1	47.3	48.3	30.0	22.5	82.4
	EGH*	88	85	84	88	93	73
PWW2B	ENERGY LOAD			51.1	36.2	61.6	
	SDHW E-W			6.8	6.5	6.6	
	TOTAL (MJ)			44.3	29.7	55.0	
	EGH*			85	88	82	
PWW2C	ENERGY LOAD			39.5	41.3		
	SDHW E-W			6.8	6.5		
	TOTAL (MJ)			32.7	34.8		
	EGH*			89	86		
1.5STOREY	ENERGY LOAD	49.6	41.4	48.5	32.8	49.4	69.7
	SDHW E-W	5.4	7.4	6.7	6.4	6.5	6.2
	TOTAL (MJ)	44.2	34.0	41.8	26.4	42.9	63.5
	EGH*	85	89	86	90	86	81
2STOREY60	ENERGY LOAD	38.2	41.4	44.5	35.4	55.2	91.3
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	32.7	34.2	37.7	28.9	48.5	85.3
	EGH*	89	89	87	89	84	74
2STOREY95	ENERGY LOAD	48.7	49.3	45.4	31.6	60.0	87.7
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	43.1	42.1	38.5	25.1	53.4	81.7
	EGH*	86	87	87	90	83	75
BUNG60	ENERGY LOAD	36.6	44.5	41.4	27.8	48.9	83.3
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	31.1	37.3	34.6	21.2	42.3	77.3
	EGH*	90	88	88	92	86	77
BUNG95	ENERGY LOAD	21.0	38.7	38.5	36.9	44.4	67.4
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	15.4	31.5	31.7	30.4	37.7	61.4
	EGH*	95	90	89	88	88	81
SPLITLEVEL	ENERGY LOAD	42.9	57.0	50.1	30.8	61.2	88.2
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	37.4	49.8	43.3	24.2	54.5	82.2
	EGH*	87	84	86	91	82	75
SPLITENTRY	ENERGY LOAD	36.1	46.7	42.4	27.6	51.6	72.9
	SDHW E-W	5.6	7.2	6.8	6.6	6.7	6.0
	TOTAL (MJ)	30.6	39.4	35.6	21.0	44.9	66.9
	EGH*	90	87	88	92	85	80
UP/DOWN	ENERGY LOAD	44.7	55.7	60.0	31.3	63.7	54.0
	SDHW E-W	5.6	7.3	6.8	6.6	6.7	6.1
	TOTAL (MJ)	39.1	48.4	53.2	24.8	57.0	48.0
	EGH*	87	85	82	90	81	85
ROWHOUSE	ENERGY LOAD	36.3	45.9	51.2	27.5	53.4	
	SDHW E-W	5.5	7.4	6.8	6.5	6.6	
	TOTAL (MJ)	30.8	38.5	44.4	21.0	46.7	
	EGH*	90	88	85	92	85	

Overall Energy Use Upgraded Envelope, Without Renewables

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	space & dhw	18.1	41.0	41.4	22.9	15.4	19.2
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	31.8	54.7	55.1	36.5	29.1	32.9
PWW2B	space & dhw	0.0	0.0	37.4	22.6	47.9	
	Appliance		13.7	13.7	13.7	13.7	
	TOTAL			51.1	36.2	61.6	
PWW2C	space & dhw		0.0	25.8	27.6		
	Appliance		13.7	13.7	13.7		
	TOTAL			39.5	41.3		
1.5STOREY	space & dhw	27.8	27.7	34.8	19.2	35.7	56.0
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	41.5	41.4	48.5	32.8	49.4	69.7
2STOREY60	space & dhw	19.7	27.7	30.8	21.7	41.5	18.5
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	33.4	41.4	44.5	35.4	55.2	32.2
2STOREY95	space & dhw	29.1	35.6	31.7	17.9	46.4	20.3
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	42.8	49.3	45.4	31.6	60.1	34.0
BUNG60	space & dhw	17.0	30.8	27.7	14.1	35.3	15.3
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	30.7	44.5	41.4	27.8	49.0	29.0
BUNG95	space & dhw	19.2	25.1	24.8	23.3	30.7	15.3
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	32.9	38.7	38.5	36.9	44.4	29.0
SPLITLEVEL	space & dhw	29.3	43.3	36.4	17.1	47.5	74.5
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	43.0	57.0	50.1	30.8	61.2	88.2
SPLITENTRY	space & dhw	22.5	33.0	28.7	13.9	37.9	59.2
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	36.2	46.7	42.4	27.6	51.6	72.9
UP/DOWN	space & dhw	31.0	42.1	46.3	17.6	50.0	40.4
	Appliance	13.7	13.7	13.7	13.7	13.7	13.7
	TOTAL	44.7	55.7	60.0	31.3	63.7	54.1
ROWHOUSE	space & dhw	22.7	32.2	37.5	13.8	39.7	
	Appliance	13.7	13.7	13.7	13.7	13.7	
	TOTAL	36.4	45.9	51.2	27.5	53.4	

Upgraded Envelope With 'Full' PV array (8760 kWh contribution annually)

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	Energy Load	31.8	54.7	55.1	36.5	29.1	32.9
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	0.3	23.2	23.6	5.0	-2.4	1.3
	EGH*	100	93	92	98	101	100
PWW2B	Energy Load			51.1	36.2	61.6	
	PV contribution			31.5	31.5	31.5	
	TOTAL (GJ)			19.5	4.7	30.1	
	EGH*			93	98	90	
PWW2C	Energy Load			39.5	41.3		
	PV contribution			31.5	31.5		
	TOTAL (GJ)			7.9	9.7		
	EGH*			97	96		
1.5STOREY	Energy Load	41.5	41.4	48.5	32.8	49.4	69.7
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	10.0	9.9	16.9	1.3	17.9	38.2
	EGH*	97	97	94	99	94	88
2STOREY60	Energy Load	33.4	41.4	44.5	35.4	55.2	32.2
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	1.8	9.8	13.0	3.9	23.7	0.7
	EGH*	99	97	96	98	92	100
2STOREY95	Energy Load	42.8	49.3	45.4	31.6	60.0	34.0
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	11.2	17.7	13.8	0.1	28.5	2.4
	EGH*	96	94	95	100	91	99
BUNG60	Energy Load	30.7	44.5	41.4	27.8	48.9	29.0
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	-0.9	13.0	9.8	-3.8	17.4	-2.6
	EGH*	100	96	97	101	94	101
BUNG95	Energy Load	32.9	38.7	38.5	36.9	44.4	29.0
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	1.4	7.2	6.9	5.4	12.9	-2.6
	EGH*	100	98	98	98	96	101
SPLITLEVEL	Energy Load	43.0	57.0	50.1	30.8	61.2	88.2
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	11.4	25.5	18.6	-0.7	29.6	56.6
	EGH*	96	92	94	100	90	83
SPLITENTRY	Energy Load	36.2	46.7	42.4	27.6	51.6	72.9
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	4.6	15.1	10.9	-3.9	20.0	41.4
	EGH*	98	95	96	102	93	87
UP/DOWN	Energy Load	44.7	55.7	60.0	31.3	63.7	54.0
	PV contribution	31.5	31.5	31.5	31.5	31.5	31.5
	TOTAL (GJ)	13.2	24.2	28.5	-0.2	32.1	22.5
	EGH*	96	92	90	100	90	93
ROWHOUSE	Energy Load	36.4	45.9	51.2	27.5	53.4	
	PV contribution	31.5	31.5	31.5	31.5	31.5	
	TOTAL (GJ)	4.8	14.3	19.6	-4.0	21.8	
	EGH*	98	95	93	102	93	

Upgraded Envelope With Solar Hot Water and Rooftop PV array

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	Energy Load	31.8	54.7	55.1	36.5	29.1	32.9
	SDHW+PV	11.3	15.8	13.3	13.3	13.3	12.3
	TOTAL (GJ)	20.5	38.9	41.8	23.3	15.8	20.6
	EGH*	93	88	86	91	95	93
PWW2B	Energy Load			51.1	36.2	61.6	
	SDHW+PV			13.4	13.3	13.3	
	TOTAL (GJ)			37.6	22.9	48.3	
	EGH*			87	91	84	
PWW2C	Energy Load			39.5	41.3		
	SDHW+PV			13.4	13.3		
	TOTAL (GJ)			26.0	27.9		
	EGH*			91	89		
1.5STOREY	Energy Load	41.5	41.4	48.5	32.8	49.4	69.7
	SDHW+PV	12.6	17.7	14.9	14.8	14.8	13.9
	TOTAL (GJ)	28.9	23.7	33.5	18.1	34.6	55.8
	EGH*	90	92	89	93	89	83
2STOREY60	Energy Load	33.4	41.4	44.5	35.4	55.2	32.2
	SDHW+PV	13.7	18.0	15.7	15.6	15.7	14.2
	TOTAL (GJ)	19.7	23.3	28.8	19.9	39.5	18.1
	EGH*	93	93	90	92	87	95
2STOREY95	Energy Load	42.8	49.3	45.4	31.6	60.0	34.0
	SDHW+PV	13.7	18.1	15.7	15.6	15.7	14.2
	TOTAL (GJ)	29.1	31.2	29.6	16.1	44.4	19.8
	EGH*	90	90	90	94	86	94
BUNG60	Energy Load	30.7	44.5	41.4	27.8	48.9	29.0
	SDHW+PV	12.1	16.1	14.0	13.8	14.0	12.6
	TOTAL (GJ)	18.6	28.4	27.4	13.9	35.0	16.4
	EGH*	94	91	91	95	89	95
BUNG95	Energy Load	32.9	38.7	38.5	36.9	44.4	29.0
	SDHW+PV	12.2	16.2	14.1	14.0	14.1	12.7
	TOTAL (GJ)	20.7	22.5	24.3	23.0	30.3	16.3
	EGH*	93	93	92	91	90	95
SPLITLEVEL	Energy Load	43.0	57.0	50.1	30.8	61.2	88.2
	SDHW+PV	11.6	15.5	13.5	13.3	13.5	12.1
	TOTAL (GJ)	31.4	41.5	36.6	17.5	47.7	76.0
	EGH*	89	87	88	93	85	77
SPLITENTRY	Energy Load	36.2	46.7	42.4	27.6	51.6	72.9
	SDHW+PV	10.2	13.8	12.1	11.9	12.0	10.8
	TOTAL (GJ)	26.0	32.8	30.3	15.7	39.5	62.1
	EGH*	91	90	90	94	87	81
UP/DOWN	Energy Load	44.7	55.7	60.0	31.3	63.7	54.0
	SDHW+PV	9.7	13.4	11.6	11.4	11.5	10.4
	TOTAL (GJ)	35.1	42.3	48.4	19.9	52.2	43.6
	EGH*	88	87	84	92	83	87
ROWHOUSE	Energy Load	36.4	45.9	51.2	27.5	53.4	
	SDHW+PV	9.6	13.6	11.6	11.6	11.5	
	TOTAL (GJ)	26.7	32.3	39.5	15.9	41.8	
	EGH*	91	90	87	94	86	

Upgraded Envelope with Solar Hot Water and 'Full' PV Array (8760 kWh)

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	Energy Load	32	55	55	37	29	33
	SDHW+FULL PV	38	41	40	40	40	39
	TOTAL (GJ)	-6	13	15	-3	-11	-6
	EGH*	102	96	95	101	103	102
PWW2B	Energy Load			51	36	62	
	SDHW+FULL PV			40	40	40	
	TOTAL (GJ)			11	-4	22	
	EGH*			96	101	93	
PWW2C	Energy Load			39	41		
	SDHW+FULL PV			40	40		
	TOTAL (GJ)			0	2		
	EGH*			100	99		
1.5STOREY	Energy Load	42	41	48	33	49	70
	SDHW+FULL PV	38	42	40	40	40	39
	TOTAL (GJ)	3	0	8	-7	10	30
	EGH*	99	100	97	103	97	91
2STOREY60	Energy Load	33	41	44	35	55	32
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	-4	1	5	-4	16	-6
	EGH*	101	100	98	101	95	102
2STOREY95	Energy Load	43	49	45	32	60	34
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	5	9	6	-7	21	-4
	EGH*	98	97	98	103	93	101
BUNG60	Energy Load	31	44	41	28	49	29
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	-7	4	2	-11	10	-9
	EGH*	102	99	99	104	97	103
BUNG95	Energy Load	33	39	38	37	44	29
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	-5	-2	-1	-2	5	-9
	EGH*	102	101	100	101	98	103
SPLITLEVEL	Energy Load	43	57	50	31	61	88
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	5	17	11	-8	22	50
	EGH*	98	95	96	103	93	85
SPLITENTRY	Energy Load	36	47	42	28	52	73
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	-2	6	3	-12	12	34
	EGH*	101	98	99	104	96	90
UP/DOWN	Energy Load	45	56	60	31	64	54
	SDHW+FULL PV	38	40	39	39	39	38
	TOTAL (GJ)	7	15	21	-8	24	16
	EGH*	98	95	93	103	92	95
ROWHOUSE	Energy Load	36	46	51	28	53	
	SDHW+FULL PV	38	40	39	39	39	
	TOTAL (GJ)	-1	5	12	-12	14	
	EGH*	100	98	96	105	95	

Change in Internal Gain

		Usable Internal Gains Fraction (%)					
		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	Base gains	19.2	17.5	16.6	17.2	15.1	17.2
	Upgrade gains	59.1	38.4	35.4	33.1	31.0	31.9
	Increase	39.9	20.9	18.8	15.9	15.9	14.7
PWW2B	Base gains			16.7	17.4	15.2	
	Upgrade gains			37.7	30.5	35.5	
	Increase			21.0	13.1	20.3	
PWW2C	Base gains			15.4	15.2		
	Upgrade gains			20.6	19.2		
	Increase			5.2	4.0		
1.5STOREY	Base gains	26.5	26.9	22.9	22.6	22.8	18.1
	Upgrade gains	44.1	50.9	44.0	35.7	45.2	37.0
	Increase	17.6	24.0	21.1	13.1	22.4	18.9
2STOREY60	Base gains	28.9	24.3	24.1	21.1	21.3	15.3
	Upgrade gains	56.7	33.7	40.7	30.0	38.5	30.0
	Increase	27.8	9.4	16.6	8.9	17.2	14.7
2STOREY95	Base gains	29.8	23.5	22.6	19.8	23.7	16.7
	Upgrade gains	44.2	40.4	38.4	35.1	35.0	29.0
	Increase	14.4	16.9	15.8	15.3	11.3	12.3
BUNG60	Base gains	25.2	29.2	27.3	23.9	23.2	20.4
	Upgrade gains	61.5	48.5	47.6	43.5	37.0	32.7
	Increase	36.3	19.3	20.3	19.6	13.8	12.3
BUNG95	Base gains	43.2	36.7	34.5	31.4	33.8	21.9
	Upgrade gains	64.1	54.2	51.4	48.2	50.9	38.8
	Increase	20.9	17.5	16.9	16.8	17.1	16.9
SPLITLEVEL	Base gains	29.3	22.8	25.3	22.0	22.1	16.5
	Upgrade gains	53.9	41.4	42.3	41.0	39.1	30.3
	Increase	24.6	18.6	17.0	19.0	17.0	13.8
SPLITENTRY	Base gains	33.3	25.2	25.5	23.8	26.2	21.1
	Upgrade gains	54.9	44.0	44.2	43.0	41.5	34.2
	Increase	21.6	18.8	18.7	19.2	15.3	13.1
UP/DOWN	Base gains	25.0	18.9	19.7	18.3	19.5	21.2
	Upgrade gains	45.1	38.3	31.3	34.8	32.2	37.0
	Increase	20.1	19.4	11.6	16.5	12.7	15.8
ROWHOUSE	Base gains	30.3	22.7	22.3	22.7	22.8	
	Upgrade gains	50.8	44.6	34.0	40.2	36.7	
	Increase	20.5	21.9	11.7	17.5	13.9	

Change in Passive Solar Gains

		Usable Solar Gains Fraction					
		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehors e
PWW2A	Base gains	12.1	13.7	9.9	12.4	10.1	13.9
	Upgrade gains	15.9	19.2	15.1	19.4	15.6	13.6
	Increase	3.8	5.5	5.2	7.0	5.5	-0.3
PWW2B	Base gains			9.9	12.5	10.2	
	Upgrade gains			15.9	20.2	17.2	
	Increase	0.0	0.0	6.0	7.7	7.0	0.0
PWW2C	Base gains			9.3	11.2		
	Upgrade gains			10.6	11.0		
	Increase	0.0	0.0	1.3	-0.2	0.0	0.0
1.5STOREY	Base gains	10.3	11.6	8.4	11.0	9.3	8.1
	Upgrade gains	16.6	14.9	10.8	16.7	13.4	10.0
	Increase	6.3	3.3	2.4	5.7	4.1	1.9
2STOREY60	Base gains	16.8	20.2	24.1	19.3	16.8	14.3
	Upgrade gains	18.4	26.9	19.7	26.1	20.8	16.9
	Increase	1.6	6.7	-4.4	6.8	4.0	2.6
2STOREY95	Base gains	20.0	23.5	19.4	21.1	21.1	15.9
	Upgrade gains	25.4	25.5	20.9	23.9	22.0	17.7
	Increase	5.4	2.0	1.5	2.8	0.9	1.8
BUNG60	Base gains	10.2	13.3	10.7	12.9	11.6	8.8
	Upgrade gains	13.0	15.8	13.8	16.5	16.7	9.3
	Increase	2.8	2.5	3.1	3.6	5.1	0.5
BUNG95	Base gains	12.9	16.3	12.9	14.7	13.5	10.8
	Upgrade gains	10.9	15.7	12.6	15.0	12.9	11.1
	Increase	-2.0	-0.6	-0.3	0.3	-0.6	0.3
SPLITLEVEL	Base gains	14.2	17.1	14.1	15.5	15.4	12.5
	Upgrade gains	14.6	18.3	15.9	17.6	17.1	13.5
	Increase	0.4	1.2	1.8	2.1	1.7	1.0
SPLITENTRY	Base gains	15.2	17.7	14.6	16.5	15.8	13.0
	Upgrade gains	14.2	19.2	16.3	18.7	17.4	13.8
	Increase	-1.0	1.5	1.7	2.2	1.6	0.8
UP/DOWN	Base gains	19.6	22.6	18.7	21.0	19.9	21.0
	Upgrade gains	20.8	25.9	21.0	25.0	23.4	24.8
	Increase	1.2	3.3	2.3	4.0	3.5	3.8
ROWHOUSE	Base gains	21.1	24.5	20.5	22.0	20.1	
	Upgrade gains	20.9	26.9	22.6	26.6	24.8	
	Increase	-0.2	2.4	2.1	4.6	4.7	

GHG emission reductions

		Vancouver	Calgary	Toronto	Montreal	Halifax	Whitehorse
PWW2A	Base GHG	15.2	16.4	15.9	24.2	22.2	21.6
	Upgrade GHG	6.6	7.3	7.2	9.2	7.5	14.1
	TOTAL	8.6	9.1	8.7	15.1	14.8	7.5
PWW2B	Base GHG			15.8	23.9	22.0	21.6
	Upgrade GHG			7.0	8.6	8.8	
	TOTAL			8.8	15.3	13.2	
PWW2C	Base GHG			16.9	27.4		
	Upgrade GHG			9.0	9.3		
	TOTAL			7.9	18.1		
1.5STOREY	Base GHG	12.2	12.3	12.4	12.4	15.3	24.1
	Upgrade GHG	8.0	6.6	6.9	8.1	7.9	12.8
	TOTAL	4.2	5.7	5.5	4.3	7.4	11.3
2STOREY60	Base GHG	10.7	12.4	11.4	18.6	15.2	25.6
	Upgrade GHG	6.8	6.5	7.6	8.5	8.4	13.9
	TOTAL	3.9	5.9	3.8	10.1	6.9	11.7
2STOREY95	Base GHG	9.5	11.3	10.0	19.5	14.6	25.3
	Upgrade GHG	8.2	7.1	7.0	7.9	8.8	14.3
	TOTAL	1.2	4.2	3.0	11.6	5.8	10.9
BUNG60	Base GHG	12.7	11.6	10.8	17.6	14.3	22.5
	Upgrade GHG	6.6	7.1	6.9	7.3	8.7	13.9
	TOTAL	6.0	4.5	4.0	10.3	5.6	8.7
BUNG95	Base GHG	7.9	9.4	8.2	14.0	11.2	21.4
	Upgrade GHG	6.4	6.5	6.4	7.1	7.6	12.7
	TOTAL	1.5	2.9	1.7	6.9	3.6	8.8
SPLITLEVEL	Base GHG	11.2	13.0	11.9	20.8	16.6	15.5
	Upgrade GHG	6.6	7.4	7.0	7.8	8.8	14.2
	TOTAL	4.6	5.6	4.9	13.1	7.8	1.3
SPLITENTRY	Base GHG	10.2	12.1	10.8	17.2	12.8	20.0
	Upgrade GHG	6.3	6.9	6.6	7.3	8.1	13.1
	TOTAL	4.0	5.3	4.2	9.9	4.7	6.9
UP/DOWN	Base GHG	10.7	12.9	12.1	21.6	16.1	15.0
	Upgrade GHG	6.7	7.3	7.5	7.8	9.0	8.3
	TOTAL	4.1	5.6	4.6	13.7	7.2	6.7
ROWHOUSE	Base GHG	9.5	11.2	10.6	18.3	14.0	
	Upgrade GHG	6.3	6.8	7.0	7.3	8.2	
	TOTAL	3.2	4.4	3.6	11.0	5.8	

Appendix E: Solar Hot Water Calculations for Canadian Cities

A study of the performance of solar water heating systems that could be applied to the roofs and walls of existing homes across Canada was carried out using RETScreen SWH ver 3. The EQuilibrium technical requirements for hot water consumption of 225 liters per day @ 55°C were assumed. Systems were modelled based on the following variables

Variables in Solar DHW modelling

Orientations	South, Southeast, Southwest, East and West
Slopes	1 in 12 to 12 in 12 and vertical (4°, 9.5°, 14°, 18.5°, 22.5°, 26.5°, 30.5°, 33.75°, 37°, 40°, 42.5°, 45°, 90° from the horizontal)
Collector areas	6 m^2, 12 m^2, 18 m^2, 24 m^2
Ratio of water storage to collector area	40 liters / m^2
Pumping energy	0 watts assuming photovoltaic powered pump or thermosyphon system
Collector types	Flat plate (Thermodynamics G 32P), evacuated tube (Thermax TMA)
Heat exchanger efficiency	85%
Desired water temperature	55 C
Locations	Vancouver, Whitehorse, Calgary, Edmonton, Saskatoon, Winnipeg, Yellow knife, Toronto, Ottawa, Montreal, Quebec, Fredricton, Charlottetown, Halifax and St, John's

For each combination of variables the percent annual solar contribution and renewable energy in GJ was calculated. In addition the collector area and storage capacity required for systems to provide 100% solar was also calculated.

General Observations

Based on the product data, weather data and the algorithms used in RETScreen and the input assumptions it appears that solar water heating systems can provide between 40% and 100% of the annual requirements in all locations modelled. The actual ability of a system to provide 100% hot water demand in all future years will be affected by variability in climate that could vary significantly from the historic weather patterns on which the weather data in RETScreen is based.

- The solar system efficiency – the percentage of incident solar energy that is converted into useful heat is also calculated by RETScreen.
- Systems with smaller areas of collectors offer higher system efficiencies with highest system efficiencies occurring with evacuated tube systems of 6m^2 in clear continental climates.
- While smaller systems offer a greater bang for the buck like any system supplying less than 100% they require full capacity conventional backup water heating systems.
- To reach the goal of net zero any fuel consumed for the backup system has to be compensated for with onsite renewable energy, this would require the use of sustainably harvested biomass or electricity produced by wind, small scale hydro or photovoltaics.
- Systems with vertically mounted collectors are likely to operate even better than predicted by RETScreen due to the fact that no snow would cover the collectors during the winter and reflection from snow ground cover would increase the amount of solar radiation received.
- Vertically mounted collectors are also less prone to overheating in the summer a problem that has been in encountered particularly with evacuated tube systems.
- Vertical arrays may also be easier to retrofit as they are wall mounted and the collectors will be typically closer to the storage tank than a roof mounted system and the piping does not need to be routed through an unheated attic space.
- The annual performance of smaller flat plate collector arrays could be improved by adjusting collector slope over the year from vertical in the winter to 30 to 45 degrees in the summer.
- Due to the capital costs of the solar domestic water heat systems the most likely scenario is that smaller systems using between 1 and 4 collectors will be used most widely with a 2 collector system with a collector area of 60 m2 being the most common.

East and West Facing Systems

For east and west facing systems there was little variation in the percent annual solar contribution to domestic water heating with change in collector slope. The exception to this being for vertically mounted collectors which are 7 to 12% less effective for the systems with $6m^2$ of collectors and between 6 and 0% less effective for systems with 24 m^2 of collectors. Although systems that used evacuated tube collectors performed significantly better for systems that have small collector areas this difference was much less pronounced for the larger systems. This presumably is due to the fact that the larger systems with larger storage capacities operate for longer periods of time at lower collector inlet temperatures than the smaller systems.

The most representative system of those typically installed today (2007) consist of $6m^2$ of collector and a 240 liter storage tank. In cloudy marine climates these systems are predicted to contribute between 38 and 48% of the annual hot water requirements for systems using flat plate collectors and between 59 and 62% for systems using evacuated tube collectors. In sunnier continental climates these systems are predicted to contribute 53% for systems using flat plate collectors and between 69 and 71% for systems using evacuated tube collectors.

An issue that is not addressed by RETScreen is variation in availability of solar radiation over the day. RETScreen assumes that east and west facing surfaces receive identical levels of radiation. This maybe the case in continental climates but based on observations in Vancouver, east facing surfaces see lower solar radiation levels than west facing surfaces due to early morning cloud cover which often burns off by late morning resulting in higher solar radiation levels on west facing surfaces in the afternoon. In addition afternoon temperatures tend to be higher than morning temperatures resulting in lower heat losses for the solar collector and therefore higher system performance.

Southeast and Southwest Systems

Southeast and Southwest facing systems collect more solar radiation per square meter than east and west facing systems for the same slope. Systems consisting of $6m^2$ of collector and a 240 liter storage tank in cloudy marine climates are predicted to contribute between 42 and 51% of the annual hot water requirements for systems using flat plate collectors and between 59 and 70% for systems using evacuated tube collectors. In sunnier continental climates these systems are predicted to contribute 55 and 68% for systems using flat plate collectors and between 71 and 86% for systems using evacuated tube collectors.

South Facing Systems

As would be expected south facing roof mounted systems with slopes in the range of 30 to 45 degrees produced the most energy per square meter of collector area although this is less pronounced in cloudy maritime climates and more pronounced in clearer continental climates. Systems consisting of $6m^2$ of collector and a 240 liter storage tank in cloudy marine climates are predicted to contribute between 42 and 53% of the annual hot water requirements for systems using flat plate collectors and between 62 and 73% for systems using evacuated tube collectors. In sunnier continental climates these systems are predicted to contribute 55 and 73% for systems using flat plate collectors and between 74 and 93% for systems using evacuated tube collectors.

Snow

The effect of snow cover in winter on the performance of solar collectors has not been accounted for as no method appears to have been developed to predict the effect of snow cover on solar collector performance. For this reason values given for sloped arrays will be higher than actual performance. As noted elsewhere vertical system performance will likely be higher than predicted due to increase solar radiation reflected from snow ground cover.

Combination Systems

With larger collector arrays and larger storage systems the use of these systems to provide a portion of the annual space heating requirements in addition to domestic water heating presents itself particularly in the spring and fall. The modelling of the performance of these combi systems is beyond the capabilities of RETScreen at this time and therefore was not pursued but should be investigated at a later time for use in net zero buildings.


Vertical evacuated collector array as part of a solar combination system

Sample tables showing all results of the RETScreen runs for Vancouver and Calgary for both flat plate and evacuated tube systems are displayed on the following pages. The tables after that summarize results for flat plate and evacuated tube systems in 15 cities across the country.

Vancouver
225 liters per day @ 55 °C Thermodynamics G 32P Flat Plate Collector 40 liters / m² storage

Direction: East / West

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	47%	7.26	12	129	58%	9.08	18	194	68%	10.64	24	258	83%
2 in 12	9.5	6	65	47%	7.26	12	129	58%	9.08	18	194	68%	10.64	24	258	83%
3 in 12	14	6	65	46%	7.15	12	129	58%	9.08	18	194	68%	10.64	24	258	83%
4 in 12	18.5	6	65	46%	7.15	12	129	58%	9.08	18	194	69%	10.66	24	258	83%
5 in 12	22.5	6	65	46%	7.15	12	129	58%	9.08	18	194	69%	10.66	24	258	83%
6 in 12	26.5	6	65	46%	7.15	12	129	58%	9.08	18	194	69%	10.66	24	258	83%
7 in 12	30.5	6	65	46%	7.10	12	129	58%	9.07	18	194	69%	10.65	24	258	83%
8 in 12	33.75	6	65	45%	7.06	12	129	58%	9.06	18	194	68%	10.64	24	258	83%
9 in 12	37	6	65	45%	7.02	12	129	58%	9.04	18	194	68%	10.62	24	258	83%
10 in 12	40	6	65	45%	6.97	12	129	58%	9.02	18	194	68%	10.60	24	258	83%
11 in 12	42.5	6	65	44%	6.92	12	129	58%	9.00	18	194	68%	10.58	24	258	83%
12 in 12	45	6	65	44%	6.87	12	129	58%	8.97	18	194	68%	10.55	24	258	83%
Vertical Wall	90	6	65	32%	4.99	12	129	48%	7.42	18	194	60%	9.34	24	258	77%

Direction: Southeast / Southwest

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	48%	7.40	12	129	59%	9.26	18	194	70%	10.89	24	258	84%
2 in 12	9.5	6	65	49%	7.56	12	129	61%	9.46	18	194	72%	11.18	24	258	86%
3 in 12	14	6	65	49%	7.67	12	129	62%	9.60	18	194	73%	11.39	24	258	87%
4 in 12	18.5	6	65	50%	7.76	12	129	63%	9.76	18	194	74%	11.57	24	258	88%
5 in 12	22.5	6	65	50%	7.83	12	129	63%	9.88	18	194	75%	11.71	24	258	89%
6 in 12	26.5	6	65	51%	7.88	12	129	64%	9.98	18	194	76%	11.83	24	258	89%
7 in 12	30.5	6	65	51%	7.91	12	129	65%	10.08	18	194	77%	11.94	24	258	90%
8 in 12	33.75	6	65	51%	7.93	12	129	65%	10.15	18	194	77%	12.01	24	258	90%
9 in 12	37	6	65	51%	7.92	12	129	66%	10.21	18	194	78%	12.07	24	258	91%
10 in 12	40	6	65	51%	7.91	12	129	66%	10.25	18	194	78%	12.12	24	258	91%
11 in 12	42.5	6	65	51%	7.88	12	129	66%	10.28	18	194	78%	12.15	24	258	91%
12 in 12	45	6	65	50%	7.85	12	129	66%	10.30	18	194	78%	12.18	24	258	91%
Vertical Wall	90	6	65	36%	5.59	12	129	55%	8.54	18	194	72%	11.20	24	258	89%

Direction: South

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	48%	7.45	12	129	60%	9.32	18	194	71%	10.99	24	258	85%
2 in 12	9.5	6	65	49%	7.67	12	129	62%	9.60	18	194	73%	11.39	24	258	87%
3 in 12	14	6	65	50%	7.82	12	129	63%	9.84	18	194	75%	11.67	24	258	88%
4 in 12	18.5	6	65	51%	7.97	12	129	65%	10.07	18	194	77%	11.92	24	258	90%
5 in 12	22.5	6	65	52%	8.07	12	129	66%	10.27	18	194	78%	12.11	24	258	91%
6 in 12	26.5	6	65	52%	8.15	12	129	67%	10.44	18	194	79%	12.28	24	258	92%
7 in 12	30.5	6	65	53%	8.22	12	129	68%	10.60	18	194	80%	12.43	24	258	92%
8 in 12	33.75	6	65	53%	8.25	12	129	69%	10.70	18	194	81%	12.53	24	258	93%
9 in 12	37	6	65	53%	8.27	12	129	69%	10.71	18	194	81%	12.63	24	258	93%
10 in 12	40	6	65	53%	8.27	12	129	70%	10.87	18	194	82%	12.70	24	258	94%
11 in 12	42.5	6	65	53%	8.26	12	129	70%	10.91	18	194	82%	12.75	24	258	94%
12 in 12	45	6	65	53%	8.24	12	129	70%	10.95	18	194	82%	12.80	24	258	94%
Vertical Wall	90	6	65	35%	5.48	12	129	57%	8.86	18	194	75%	11.73	24	258	94%

Vancouver
225 liters per day @ 55 °C Thermax TMA Evacuated Tube Collector 40 liters / m² storage

Direction East / West

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	62.00%	9.65	12	129	73.00%	11.42	18	194	79%	12.22	24	258	82.00%
2 in 12	9.5	6	65	62.00%	9.65	12	129	73.00%	11.42	18	194	79%	12.23	24	258	82.00%
3 in 12	14	6	65	62.00%	9.65	12	129	73.00%	11.43	18	194	79%	12.24	24	258	82.00%
4 in 12	18.5	6	65	62.00%	9.65	12	129	74.00%	11.44	18	194	79%	12.25	24	258	82.00%
5 in 12	22.5	6	65	62.00%	9.65	12	129	74.00%	11.44	18	194	79%	12.25	24	258	82.00%
6 in 12	26.5	6	65	62.00%	9.64	12	129	74.00%	11.44	18	194	79%	12.26	24	258	82.00%
7 in 12	30.5	6	65	62.00%	9.63	12	129	74.00%	11.44	18	194	79%	12.26	24	258	82.00%
8 in 12	33.75	6	65	62.00%	9.61	12	129	74.00%	11.43	18	194	79%	12.25	24	258	82.00%
9 in 12	37	6	65	62.00%	9.59	12	129	73.00%	11.42	18	194	79%	12.25	24	258	82.00%
10 in 12	40	6	65	62.00%	9.57	12	129	73.00%	11.41	18	194	79%	12.23	24	258	82.00%
11 in 12	42.5	6	65	61.00%	9.55	12	129	73.00%	11.39	18	194	79%	12.22	24	258	82.00%
12 in 12	45	6	65	61.00%	9.52	12	129	73.00%	11.37	18	194	78%	12.21	24	258	82.00%
Vertical Wall	90	6	65	51.00%	7.89	12	129	67.00%	10.36	18	194	72%	11.24	24	258	76.00%

Direction Southeast / Southwest

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	63.00%	9.84	12	129	75%	11.63	18	194	80%	12.43	24	258	83%
2 in 12	9.5	6	65	65.00%	10.07	12	129	76%	11.90	18	194	82%	12.70	24	258	85%
3 in 12	14	6	65	66.00%	10.24	12	129	78%	12.08	18	194	83%	12.89	24	258	86%
4 in 12	18.5	6	65	67.00%	10.39	12	129	79%	12.24	18	194	84%	13.06	24	258	87%
5 in 12	22.5	6	65	68.00%	10.51	12	129	79%	12.36	18	194	85%	13.19	24	258	88%
6 in 12	26.5	6	65	68.00%	10.61	12	129	80%	12.47	18	194	85%	13.29	24	258	89%
7 in 12	30.5	6	65	69.00%	10.69	12	129	81%	12.56	18	194	86%	13.38	24	258	89%
8 in 12	33.75	6	65	69.00%	10.75	12	129	81%	12.63	18	194	86%	13.44	24	258	90%
9 in 12	37	6	65	69.00%	10.79	12	129	82%	12.69	18	194	87%	13.49	24	258	90%
10 in 12	40	6	65	70.00%	10.82	12	129	82%	12.73	18	194	87%	13.54	24	258	90%
11 in 12	42.5	6	65	70.00%	10.84	12	129	82%	12.76	18	194	87%	13.57	24	258	90%
12 in 12	45	6	65	70.00%	10.85	12	129	82%	12.79	18	194	87%	13.59	24	258	91%
Vertical Wall	90	6	65	59.00%	9.11	12	129	79%	13.23	18	194	85%	13.21	24	258	89%

Direction South

Slope Rise and Run	Slope	Collector Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collect or Area		% Solar Fraction of Annual DHW
Inches	Degrees	m²	ft²			m²	ft²			m²	ft²			m²	ft²	
1 in 12	4	6	65	64.00%	9.91	12	129	75%	11.72	18	194	80%	12.52	24	258	84%
2 in 12	9.5	6	65	66.00%	10.24	12	129	78%	12.08	18	194	83%	12.89	24	258	86%
3 in 12	14	6	65	67.00%	10.48	12	129	79%	12.32	18	194	85%	13.15	24	258	88%
4 in 12	18.5	6	65	69.00%	10.69	12	129	81%	12.54	18	194	86%	13.36	24	258	89%
5 in 12	22.5	6	65	70.00%	10.85	12	129	82%	12.72	18	194	87%	13.52	24	258	90%
6 in 12	26.5	6	65	71.00%	11.00	12	129	83%	12.87	18	194	88%	13.66	24	258	91%
7 in 12	30.5	6	65	71.00%	11.12	12	129	84%	13.01	18	194	89%	13.79	24	258	92%
8 in 12	33.75	6	65	72.00%	11.21	12	129	84%	13.11	18	194	89%	13.88	24	258	92%
9 in 12	37	6	65	72.00%	11.28	12	129	85%	13.20	18	194	90%	13.96	24	258	93%
10 in 12	40	6	65	73.00%	11.33	12	129	85%	13.27	18	194	90%	14.02	24	258	93%
11 in 12	42.5	6	65	73.00%	11.37	12	129	85%	13.32	18	194	90%	14.07	24	258	93%
12 in 12	45	6	65	73.00%	11.40	12	129	85%	13.36	18	194	91%	14.11	24	258	93%
Vertical Wall	90	6	65	59.00%	9.12	12	129	84%	13.10	18	194	90%	14.01	24	258	93%

Calgary
225 liters per day @ 55 °C Thermodynamics G 32P Flat Plate Collector 40 liters / m² storage

Direction
East / West

Slope Rise and Run Inches	Slope Degrees	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW
1 in 12	4	6	65	53%	9.28	12	129	67%	11.67	18	194	76%	13.27	24	258	87%
2 in 12	9.5	6	65	53%	9.29	12	129	67%	11.72	18	194	76%	13.33	24	258	87%
3 in 12	14	6	65	53%	9.31	12	129	67%	11.79	18	194	76%	13.39	24	258	87%
4 in 12	18.5	6	65	53%	9.33	12	129	68%	11.86	18	194	77%	13.48	24	258	88%
5 in 12	22.5	6	65	53%	9.35	12	129	68%	11.93	18	194	77%	13.56	24	258	88%
6 in 12	26.5	6	65	53%	9.36	12	129	69%	12.01	18	194	78%	13.64	24	258	89%
7 in 12	30.5	6	65	53%	9.36	12	129	69%	12.08	18	194	78%	13.71	24	258	89%
8 in 12	33.75	6	65	53%	9.37	12	129	69%	12.13	18	194	79%	13.77	24	258	90%
9 in 12	37	6	65	53%	9.36	12	129	70%	12.18	18	194	79%	13.83	24	258	90%
10 in 12	40	6	65	53%	9.36	12	129	70%	12.22	18	194	79%	13.88	24	258	90%
11 in 12	42.5	6	65	53%	9.34	12	129	70%	12.25	18	194	79%	13.92	24	258	90%
12 in 12	45	6	65	53%	9.32	12	129	70%	12.28	18	194	80%	13.95	24	258	90%
Vertical Wall	90	6	65	44%	7.63	12	129	65%	11.41	18	194	78%	13.59	24	258	90%

Direction
Southeast / Southwest

Slope Rise and Run Inches	Slope Degrees	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW
1 in 12	4	6	65	55%	9.63	12	129	69%	12.17	18	194	79%	13.79	24	258	89%
2 in 12	9.5	6	65	58%	10.16	12	129	73%	12.80	18	194	82%	14.41	24	258	92%
3 in 12	14	6	65	60%	10.55	12	129	76%	13.26	18	194	85%	14.82	24	258	94%
4 in 12	18.5	6	65	62%	10.91	12	129	78%	13.67	18	194	87%	15.18	24	258	96%
5 in 12	22.5	6	65	64%	11.19	12	129	80%	13.98	18	194	88%	15.46	24	258	97%
6 in 12	26.5	6	65	65%	11.43	12	129	81%	14.27	18	194	89%	15.56	24	258	97%
7 in 12	30.5	6	65	65%	11.42	12	129	82%	14.41	18	194	90%	15.76	24	258	97%
8 in 12	33.75	6	65	66%	11.56	12	129	83%	14.59	18	194	91%	15.91	24	258	98%
9 in 12	37	6	65	67%	11.68	12	129	84%	14.75	18	194	92%	16.04	24	258	98%
10 in 12	40	6	65	67%	11.76	12	129	85%	14.88	18	194	92%	16.15	24	258	98%
11 in 12	42.5	6	65	67%	11.82	12	129	86%	14.98	18	194	93%	16.22	24	258	99%
12 in 12	45	6	65	68%	11.86	12	129	86%	15.06	18	194	93%	16.29	24	258	99%
Vertical Wall	90	6	65	57%	9.98	12	129	82%	14.36	18	194	92%	16.18	24	258	100%

Direction
South

Slope Rise and Run Inches	Slope Degrees	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m²	ft²	% Solar Fraction of Annual DHW
1 in 12	4	6	65	55%	9.62	12	129	70%	12.27	18	194	79%	13.82	24	258	89%
2 in 12	9.5	6	65	59%	10.34	12	129	75%	13.12	18	194	84%	14.64	24	258	93%
3 in 12	14	6	65	62%	10.86	12	129	78%	13.71	18	194	85%	15.17	24	258	95%
4 in 12	18.5	6	65	65%	11.31	12	129	81%	14.23	18	194	89%	15.61	24	258	97%
5 in 12	22.5	6	65	67%	11.67	12	129	83%	14.62	18	194	91%	15.93	24	258	98%
6 in 12	26.5	6	65	68%	11.98	12	129	85%	14.97	18	194	93%	16.21	24	258	99%
7 in 12	30.5	6	65	70%	12.24	12	129	87%	15.27	18	194	94%	16.42	24	258	99%
8 in 12	33.75	6	65	71%	12.42	12	129	88%	15.48	18	194	95%	16.57	24	258	99%
9 in 12	37	6	65	72%	12.56	12	129	89%	15.67	18	194	95%	16.69	24	258	100%
10 in 12	40	6	65	72%	12.67	12	129	90%	15.82	18	194	96%	16.78	24	258	100%
11 in 12	42.5	6	65	73%	12.74	12	129	91%	15.93	18	194	96%	16.85	24	258	100%
12 in 12	45	6	65	73%		12	129	92%	16.03	18	194	97%	16.91	24	258	100%
Vertical Wall	90	6	65	60%	10.55	12	129	85%	14.86	18	194	94%	16.54	24	258	99%

Calgary
225 liters per day @ 55 °C Thermax TMA Evacuated Tube Collector 40 liters / m² storage

Direction
East / West

Slope Rise and Run Inches	Slope Degrees	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW
1 in 12	4	6	65	69%	12.06	12	129	82%	14.36	18	194	87%	15.30	24	258	91%
2 in 12	9.5	6	65	69%	12.10	12	129	82%	14.41	18	194	88%	15.35	24	258	91%
3 in 12	14	6	65	69%	12.14	12	129	83%	14.47	18	194	88%	15.41	24	258	91%
4 in 12	18.5	6	65	70%	12.20	12	129	83%	14.55	18	194	88%	15.49	24	258	92%
5 in 12	22.5	6	65	70%	12.25	12	129	83%	14.62	18	194	89%	15.56	24	258	92%
6 in 12	26.5	6	65	70%	12.30	12	129	84%	14.69	18	194	89%	15.63	24	258	92%
7 in 12	30.5	6	65	70%	12.35	12	129	84%	14.76	18	194	89%	15.70	24	258	93%
8 in 12	33.75	6	65	70%	12.38	12	129	85%	14.82	18	194	90%	15.76	24	258	93%
9 in 12	37	6	65	71%	12.42	12	129	85%	14.82	18	194	90%	15.82	24	258	93%
10 in 12	40	6	65	71%	12.44	12	129	85%	14.92	18	194	91%	15.87	24	258	93%
11 in 12	42.5	6	65	71%	12.46	12	129	85%	14.96	18	194	91%	15.90	24	258	93%
12 in 12	45	6	65	71%	12.47	12	129	86%	14.99	18	194	91%	15.94	24	258	94%
Vertical Wall	90	6	65	64%	11.29	12	129	85%	14.95	18	194	92%	16.03	24	258	94%

Direction
Southeast / Southwest

Slope Rise and Run Inches	Slope Degrees	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW
1 in 12	4	6	65	71%	12.47	12	129	85%	14.81	18	194	90%	15.73	24	258	93%
2 in 12	9.5	6	65	74%	13.01	12	129	88%	15.35	18	194	93%	16.21	24	258	95%
3 in 12	14	6	65	76%	13.39	12	129	90%	15.70	18	194	94%	16.51	24	258	97%
4 in 12	18.5	6	65	78%	13.74	12	129	91%	16.02	18	194	96%	16.77	24	258	98%
5 in 12	22.5	6	65	80%	14.02	12	129	93%	16.27	18	194	97%	16.96	24	258	99%
6 in 12	26.5	6	65	82%	14.28	12	129	94%	16.46	18	194	98%	17.13	24	258	99%
7 in 12	30.5	6	65	83%	14.51	12	129	95%	16.62	18	194	98%	17.25	24	258	99%
8 in 12	33.75	6	65	84%	14.67	12	129	96%	16.74	18	194	99%	17.32	24	258	100%
9 in 12	37	6	65	85%	14.82	12	129	96%	16.85	18	194	99%	17.38	24	258	100%
10 in 12	40	6	65	85%	14.94	12	129	97%	16.94	18	194	99%	17.41	24	258	100%
11 in 12	42.5	6	65	86%	15.03	12	129	97%	17.01	18	194	100%	17.43	24	258	100%
12 in 12	45	6	65	86%	15.12	12	129	97%	17.07	18	194	100%	17.45	24	258	100%
Vertical Wall	90	6	65	80%	13.98	12	129	99%	17.32	18	194	100%	17.52	24	258	100%

Direction
South

Slope Rise and Run Inches	Slope Degrees	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW	Renewable Energy Delivered in GJ	Collector Area m^2	Collector Area ft^2	% Solar Fraction of Annual DHW
1 in 12	4	6	65	72%	12.64	12	129	86%	14.99	18	194	91%	15.89	24	258	93%
2 in 12	9.5	6	65	76%	13.36	12	129	90%	15.68	18	194	94%	16.49	24	258	96%
3 in 12	14	6	65	79%	13.87	12	129	92%	16.15	18	194	96%	16.86	24	258	98%
4 in 12	18.5	6	65	82%	14.34	12	129	94%	16.50	18	194	98%	17.16	24	258	99%
5 in 12	22.5	6	65	84%	14.7	12	129	96%	16.76	18	194	99%	17.33	24	258	100%
6 in 12	26.5	6	65	86%	15.02	12	129	97%	16.98	18	194	99%	17.42	24	258	100%
7 in 12	30.5	6	65	87%	15.31	12	129	98%	17.17	18	194	100%	17.49	24	258	100%
8 in 12	33.75	6	65	89%	15.52	12	129	99%	17.17	18	194	100%	17.52	24	258	100%
9 in 12	37	6	65	90%	15.72	12	129	99%	17.37	18	194	100%	17.52	24	258	100%
10 in 12	40	6	65	91%	15.88	12	129	99%	17.41	18	194	100%	17.52	24	258	100%
11 in 12	42.5	6	65	91%	16.00	12	129	100%	17.44	18	194	100%	17.52	24	258	100%
12 in 12	45	6	65	92%	16.11	12	129	100%	17.46	18	194	100%	17.52	24	258	100%
Vertical Wall	90	6	65	83%	14.56	12	129	100%	17.52	18	194	100%	17.52	24	258	100%

Overview of Results for Solar DHW Flat Plate Solar Collector 40 l/m^2 Storage 225 l/day @ 55^{o}C

	Ranges of Annual Solar Contribution to Domestic Water Heating in % For slopes 1in12 to 12in12											
	Orientation											
	E / W				SE / SW				S			
	Collector Area in m^2											
City	6	12	18	24	6	12	18	24	6	12	18	24
Vancouver	44 to 47%	58%	68%	83%	48 to 51%	59 to 66%	70 to 78%	84 to 91%	48 to 53%	60 to 70%	71 to 82%	85 to 94%
Clagary	53%	67 to 70%	76 to 80%	87 to 90%	55 to 68%	69 to 86%	79 to 93%	89 to 99%	55 to 73%	70 to 92%	79 to 97%	93 to 100%
Edmonton	49 to 50%	63 to 66%	70 to 75%	82 to 87%	51 to 65%	65 to 83%	74 to 91%	85 to 98%	51 to 70%	66 to 89%	85 to 95%	86 to 100%
Whitehorse	38 to 39%	50 to 52%	56 to 58%	62 to 65%	38 to 46%	51 to 61%	58 to 69%	64 to 80%	32 to 49%	52 to 66%	58 to 74%	65 to 86%
Saskatoon	53 to 54%	65 to 69%	74 to 79%	87 to 91%	55 to 70%	67 to 86%	77 to 93%	89 to 100%	55 to 75%	69 to 91%	79 to 97%	91 to 100%
Winnipeg	50%	63 to 66%	73 to 76%	86 to 89%	52 to 63%	65 to 80%	76 to 90%	88 to 98%	52 to67%	66 to 86%	77 to 94%	89 to 100%
Yellowknife	41to 42%	51 to 54%	57 to 60%	66 to 70%	42 to 51%	53 to 63%	59 to 74%	68 to 87%	42 to 52%	53 to 69%	60 to 80%	69 to 92%
Toronto	51 to 53%	68%	79 to 80%	91 to 92%	55 to 61%	70 to 80%	81 to 90%	93 to 99%	55 to 64%	71 to 84%	83 to 93 %	93 to 99%
Ottawa	51 to 53%	68%	79 to 80%	91 to 92%	55 to 61%	70 to 80%	81 to 90%	93 to 99%	55 to 64%	71 to 84%	82 to 93 %	93 to 100%
Montreal	46 to 48%	64%	75%	87 to 88%	50 to 56%	68 to 76%	76 to 87%	89 to 96%	50 to 59%	67 to 81 %	77% to 90%	89 to 99%
Quebec	49 to 50%	67 to 68%	76 to 78%	88 to 90%	52 to 61%	69 to 82%	78 to 90%	90 to 98%	53 to 65%	70 to 88%	79 to 94%	91 to 100%
Fredricton	46 to 48%	65%	75 to 76%	85 to 88%	49 to 56%	67 to 78%	77 to 88%	89 to 97%	50 to 60 %	66 to 83%	78 to 92%	89 to 99%
Charlottetown	46 to 48%	64 to 65%	74 to 75%	86 to 87%	50 to 57%	66 to 78%	76 to 87%	88 to 96%	50 to 60 %	67 to 82%	77 to 91%	88 to 98%
Halifax	45 to 48%	65 to 66%	76 to 77%	89%	49 to 56%	68 to78%	78 to 88%	90 to 97%	50 to 59%	69 to 82%	79 to 92%	91 to 99%
Saint John's	38 to 41%	56 to 57%	67%	79%	42 to 46%	59 to 67%	69 to 78%	80 to 89%	42 to 49%	59 to 71%	69 to 83%	81 to 93%

	Annual Solar Contribution to Domestic Water Heating in % For Vertical Collector Array (Ground Reflection not Accounted For)											
	Orientation											
	E / W				SE / SW				S			
	Collector Area m^2											
City	6	12	18	24	6	12	18	24	6	12	18	24
Vancouver	32%	48%	60%	77%	36%	55%	72%	89%	35%	57%	75%	94%
Clagary	44%	65%	78%	90%	57%	82%	92%	100%	60%	85%	94%	99%
Edmonton	41%	62%	74%	87%	55%	80%	91%	99%	59%	84%	94%	99%
Whitehorse	31%	48%	56%	64%	37%	57%	69%	83%	39%	61%	75%	89%
Saskatoon	45%	66%	78%	91%	60%	85%	94%	100%	64%	88%	97%	100%
Winnipeg	40%	61%	74%	88%	52%	76%	89%	98%	54%	79%	91%	99%
Yellowknife	37%	53%	60%	71%	44%	64%	77%	90%	47%	70%	84%	95%
Toronto	37%	58%	72%	89%	45%	69%	84%	98%	45%	70%	85%	98%
Ottawa	37%	58%	72%	89%	45%	69%	84%	98%	45%	70%	85%	98%
Montreal	35%	54%	68%	84%	42%	65%	80%	95%	43%	67%	82%	96%
Quebec	38%	59%	73%	87%	48%	73%	86%	97%	50%	74%	87%	96%
Fredricton	34%	54%	69%	84%	43%	67%	81%	95%	32%	68%	83%	96%
Charlottetown	35%	54%	68%	83%	43%	67%	81%	94%	44%	68%	83%	95%
Halifax	33%	53%	68%	85%	41%	65%	80%	95%	42%	66%	81%	95%
Saint John's	27%	44%	57%	72%	33%	54%	69%	84%	34%	56%	72%	87%

Overview of Results for Solar DHW Evacuated Tube Solar Collector 40 l/m^2 Storage 225 l/day @ 55^{o}C

	Ranges of Annual Solar Contribution to Domestic Water Heating in % For slopes 1in12 to 12in12											
	Orientation											
	E / W				SE / SW				S			
	Collector Area in m^2											
City	6	12	18	24	6	12	18	24	6	12	18	24
Vancouver	61 to 62%	73%	78 to 79%	82%	63 to 70%	75 to 82%	80 to 87%	83 to 91%	64 to 73%	75 to 85%	80 to 91%	84 to 93%
Clagary	69 to 71%	82 to 86%	87 to 91%	91 to 94%	71 to 86%	85 to 97%	90 to 100%	93 to 100%	74 to 93%	87 to 100%	92 to 100%	95 to 100%
Edmonton	65 to 69%	78 to 82%	83 to 85%	86 to 91%	68 to 84%	81 to 95%	86 to 99%	89 to 99%	69 to 89%	82 to 99%	87 to 100%	90 to 100%
Whitehorse	51 to 53%	61 to 64%	65 to 68%	68 to 70%	52 to 83%	63 to 75%	67 to 80%	69 to 84%	53 to 68 %	63 to 80%	68 to 86%	70 to 89%
Saskatoon	68 to 71%	80 to 84%	86 to 90%	89 to 93%	70 to 87%	83 to 97%	88 to 99%	91 to 100%	71 to 92%	84 to 100%	89 to 100%	92 to 100%
Winnipeg	67 to 68%	79 to 82%	85 to 88%	89 to 91%	68 to 81%	81 to 94%	87 to 98%	91 to 99%	69 to 87%	82 to 98%	88 to 100%	91 to 100%
Yellowknife	52 to 55%	61 to 64%	65 to 67%	66 to 69%	54 to 66%	62 to 77%	66 to 82%	68 to 86%	54 to 71%	63 to 83%	66 to 88%	68 to 91%
Toronto	71%	85%	90 to 91%	93 to 94%	65%	86 to 94%	92 to 98%	94 to 99%	73 to 85%	87 to 97%	92 to 99%	95 to 100%
Ottawa	68%	82 to 83%	88 to 89%	91 to 92%	69 to 78%	83 to 92%	89 to 96%	92 to 98%	70 to 82%	84 to 95%	90 to 98%	92 to 99%
Montreal	67%	81 to 82%	87 to 88%	90 to 91%	69 to 77%	83 to 92%	89 to 96%	92 to 98%	69 to 81%	83 to 95%	89 to 98%	92 to 99%
Quebec	69 to 70%	83 to 85%	89 to 91%	92 to 94%	71 to 82%	85 to 95%	91 to 99%	93 to 100%	72 to 87%	85 to 98%	91 to 100%	94 to 100%
Fredricton	67%	82 to 84%	88 to 90%	92 to 93%	69 to 78%	84 to 94%	90 to 97%	93 to 99%	70 to 82%	85 to 96%	90 to 99%	93 to 100%
Charlottetown	67%	82 to 83%	88 to 89%	91 to 92%	69 to 78%	84 to 93%	89 to 97%	92 to 98%	70 to 82%	84 to 96%	90 to 99%	93 to 100%
Halifax	67 to 69%	84 to 85%	90 to 91%	93%	70 to 78%	85 to 94%	91 to 98%	94 to 99%	71 to 82%	86 to 97%	92 to 99%	94 to 100%
Saint John's	59 to 60%	76 to 77%	82 to 83%	86 to 87%	62 to 68%	78 to 87%	84 to 93%	88 to 95%	62 to 81%	78 to 91%	85 to 95%	88 to 98

	Annual Solar Contribution to Domestic Water Heating in % For Vertical Collector Array (Ground Reflection Not Accounted For)											
	Orientation											
	E / W				SE / SW				S			
	Collector Area m^2											
City	6	12	18	24	6	12	18	24	6	12	18	24
Vancouver	51%	67%	72%	76%	59%	79%	85%	89%	59%	84%	90%	93%
Clagary	64%	85%	92%	94%	80%	99%	100%	100%	83%	100%	100%	100%
Edmonton	62%	82%	88%	92%	78%	97%	99%	100%	82%	100%	100%	100%
Whitehorse	47%	63%	68%	70%	57%	77%	83%	87%	60%	84%	90%	92%
Saskatoon	67%	85%	91%	94%	83%	99%	100%	100%	86%	100%	100%	100%
Winnipeg	62%	81%	87%	91%	74%	95%	99%	100%	77%	99%	100%	100%
Yellowknife	52%	64%	68%	70%	64%	80%	86%	90%	68%	87%	92%	95%
Toronto	60%	81%	88%	91%	69%	93%	97%	98%	69%	97%	99%	100%
Ottawa	57%	80%	86%	89%	66%	91%	96%	97%	67%	95%	98%	99%
Montreal	56%	79%	86%	89%	65%	91%	95%	97%	66%	94%	98%	99%
Quebec	60%	82%	89%	92%	71%	94%	98%	99%	73%	98%	100%	100%
Fredricton	56%	80%	87%	91%	66%	93%	97%	98%	67%	96%	99%	100%
Charlottetown	56%	80%	86%	90%	66%	92%	97%	98%	67%	95%	99%	100%
Halifax	55%	80%	88%	91%	64%	92%	97%	98%	65%	95%	99%	100%
Saint John's	47%	71%	80%	84%	54%	83%	91%	94%	55%	86%	96%	98%

Potential for Solar Contribution and Domestic Hot Water Use

The following tables summarize the range of solar energy contributions to annual water heating requirements that are possible with a typical system of 6 m^2 of flat plate collector and 240 liters of storage for typical existing housing types across Canada assuming the collectors are mounted on the roof at the existing roof slope.

The amount of hot water consumed in the home has a significant effect the total percent of the hot water the solar system can supply. The initial assumption used in modelling was that 225 liters per day at 55^{o}C hot water would be used; this is based on the EQuilibrium program requirements. If this consumption can be reduced to 150 liter per day the same sized solar dhw system can contribute between 8 to 12% more of the total annual hot water requirements depending on orientation. Water conservation of course carries other benefits for the water supply system and the waste water treatment system that service the home. In addition as water metering becomes more common water conservation will translate into direct economic benefits for the home owner. For this reason these tables include predicted annual solar contribution based on both 225 and 150 liters per day.

6 m^2 flat palte solar collector array with 240 liter storage tank

			225 liters per day consumption @ 55oC					150 liters per day consumption @ 55oC			
Location	Age / Description	Typical Roof Slope	East / West		South			East / West		South	
			% Annual Solar Contribution	Annual Energy Delioverd in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ		% Annual Solar Contribution	Annual Energy Delioverd in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ
Vancouver											
	Pre War	9 in 12	45%	7.02	53%	8.27		53%	5.49	63%	6.5
	Post War One and Half Storey	12 in 12	44%	6.87	53%	8.24		52%	5.42	63%	6.55
	1960 - 1970	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
	Post 60's	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
	Split Level	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
	Split Entry	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
	Up - Down Duplex	6 in 12	46%	7.15	52%	8.15		54%	5.55	61%	6.33
	Row House	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
	Row House	8 in 12	45%	7.06	53%	8.25		53%	5.52	62%	6.46
	Post 1995	4 in 12	46%	7.15	51%	7.97		54%	5.57	59%	6.13
Whitehorse											
	Pre War	9 in 12	42%	7.81	53%	9.75		50%	6.17	62%	7.65
	Post War One and Half Storey	12 in 12	42%	7.84	54%	10.04		50%	6.24	64%	7.92
	1960 - 1970	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
	Post 60's	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
	Split Level	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
	Split Entry	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
	Up - Down Duplex	6 in 12	42%	7.72	50%	9.34		49%	6.05	58%	7.24
	Row House	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
	Row House	8 in 12	42%	7.79	52%	9.63		50%	6.13	61%	7.51
	Post 1995	4 in 12	41%	7.64	48%	8.89		48%	5.98	56%	6.91
Clagary											
	Pre War	9 in 12	53%	9.36	72%	12.56		63%	7.37	84%	9.85
	Post War One and Half Storey	12 in 12	53%	9.32	73%	12.74		63%	7.4	87%	10.11
	1960 - 1970	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
	Post 60's	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
	Split Level	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
	Split Entry	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
	Up - Down Duplex	6 in 12	53%	9.36	68%	11.98		62%	7.29	80%	9.35
	Row House	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
	Row House	8 in 12	53%	9.37	71%	12.42		63%	7.35	83%	9.71
	Post 1995	4 in 12	53%	9.33	65%	11.31		62%	7.21	76%	8.83
Edmonton											
	Pre War	9 in 12	50%	8.82	68%	12.19		60%	7.12	81%	9.65
	Post War One and Half Storey	12 in 12	49%	8.8	70%	12.46		60%	7.17	84%	9.95
	1960 - 1970	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55
	Post 60's	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55
	Split Level	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55
	Split Entry	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55
	Up - Down Duplex	6 in 12	49%	8.8	65%	11.54		59%	7.02	77%	9.11
	Row House	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55
	Row House	8 in 12	50%	8.81	68%	12.02		60%	7.09	80%	9.5
	Post 1995	4 in 12	49%	8.77	61%	10.83		59%	6.95	72%	8.55

6 m^2 flat palte solar collector array with 240 liter storage tank

			225 liters per day consumption @ 55oC					150 liters per day consumption @ 55oC			
Location	Age / Description	Typical Roof Slope	East / West		South			East / West		South	
			% Annual Solar Contribution	Annual Energy Deliovered in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ		% Annual Solar Contribution	Annual Energy Deliovered in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ
Saskatoon											
	Pre War	9 in 12	54%	9.52	74%	13.07		63%	7.39	84%	9.95
	Post War One and Half Storey	12 in 12	54%	9.5	75%	13.35		63%	7.45	87%	10.24
	1960 - 1970	4 in 12	54%	9.52	66%	11.61		61%	7.21	75%	8.87
	Post 60's	4 in 12	53%	9.39	66%	11.61		61%	7.21	75%	8.87
	Split Level	4 in 12	53%	9.39	66%	11.61		61%	7.21	75%	8.87
	Split Entry	4 in 12	53%	9.39	66%	11.61		61%	7.21	75%	8.87
	Up - Down Duplex	6 in 12	53%	9.47	70%	12.37		62%	7.29	80%	9.41
	Row House	4 in 12	53%	9.39	66%	11.61		61%	7.21	75%	8.87
	Row House	8 in 12	54%	9.52	73%	12.9		62%	7.36	83%	9.8
	Post 1995	4 in 12	53%	9.39	66%	11.61		61%	7.21	75%	8.87
Winnipeg											
	Pre War	9 in 12	50%	8.83	66%	11.68		60%	7.02	78%	9.18
	Post War One and Half Storey	12 in 12	50%	8.75	67%	11.85		60%	7.03	80%	9.42
	1960 - 1970	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
	Post 60's	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
	Split Level	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
	Split Entry	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
	Up - Down Duplex	6 in 12	50%	8.86	64%	11.19		59%	6.96	74%	8.73
	Row House	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
	Row House	8 in 12	50%	8.84	66%	11.56		60%	7	77%	9.06
	Post 1995	4 in 12	50%	8.85	60%	10.62		59%	6.91	70%	8.27
Toronto											
	Pre War	9 in 12	52%	8.43	64%	10.51		62%	6.77	77%	8.39
	Post War One and Half Storey	12 in 12	51%	8.27	64%	10.5		61%	6.7	78%	8.47
	1960 - 1970	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Post 60's	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Split Level	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Split Entry	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Up - Down Duplex	6 in 12	52%	8.58	63%	10.31		62%	6.8	74%	8.12
	Row House	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Row House	8 in 12	52%	8.49	64%	10.48		62%	6.79	76%	8.32
	Post 1995	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
Ottawa											
	Pre War	9 in 12	52%	8.43	64%	10.51		62%	6.77	77%	8.39
	Post War One and Half Storey	12 in 12	51%	8.27	64%	10.5		61%	6.7	78%	8.47
	1960 - 1970	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Post 60's	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Split Level	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Split Entry	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Up - Down Duplex	6 in 12	52%	8.58	63%	10.31		62%	6.8	74%	8.12
	Row House	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
	Row House	8 in 12	52%	8.49	64%	10.48		62%	6.79	76%	8.32
	Post 1995	4 in 12	53%	8.64	61%	9.98		62%	6.81	72%	7.82
Montreal											
	Pre War	9 in 12	47%	7.93	59%	9.97		58%	6.5	73%	8.15
	Post War One and Half Storey	12 in 12	46%	7.78	59%	9.98		57%	6.44	73%	8.22
	1960 - 1970	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
	Post 60's	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
	Split Level	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
	Split Entry	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
	Up - Down Duplex	6 in 12	48%	8.06	58%	9.73		58%	6.55	70%	7.88
	Row House	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
	Row House	8 in 12	47%	7.98	59%	9.92		58%	6.52	72%	8.08
	Post 1995	4 in 12	48%	8.12	56%	9.38		58%	6.56	67%	7.58
Quebec											
	Pre War	9 in 12	50%	8.63	65%	11.23		61%	7.12	79%	9.12
	Post War One and Half Storey	12 in 12	49%	8.51	65%	11.31		61%	7.09	80%	9.25
	1960 - 1970	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37
	Post 60's	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37
	Split Level	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37
	Split Entry	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37
	Up - Down Duplex	6 in 12	50%	8.7	63%	10.87		61%	7.12	76%	8.76
	Row House	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37
	Row House	8 in 12	50%	8.66	64%	11.14		61%	7.12	78%	9.03
	Post 1995	4 in 12	50%	8.72	60%	10.4		61%	7.09	72%	8.37

6 m^2 flat palte solar collector array with 240 liter storage tank

			225 liters per day consumption @ 55oC					150 liters per day consumption @ 55oC			
Location	Age / Description	Typical Roof Slope	East / West		South			East / West		South	
			% Annual Solar Contribution	Annual Energy Delioverd in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ		% Annual Solar Contribution	Annual Energy Delioverd in GJ	% Annual Solar Contribution	Annual Energy Collected in GJ
Fredricton											
	Pre War	9 in 12	47%	7.98	60%	10.23		58%	6.65	74%	8.43
	Post War One and Half Storey	12 in 12	46%	7.83	60%	10.27		58%	6.58	75%	8.51
	1960 - 1970	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
	Post 60's	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
	Split Level	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
	Split Entry	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
	Up - Down Duplex	6 in 12	47%	8.11	58%	996		59%	6.67	72%	8.15
	Row House	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
	Row House	8 in 12	47%	8.03	60%	10.17		58%	6.66	73%	8.37
	Post 1995	4 in 12	48%	8.16	56%	9.58		59%	6.68	69%	7.82
Charlottetown											
	Pre War	9 in 12	47%	8.08	60%	10.27		58%	6.68	74%	8.44
	Post War One and Half Storey	12 in 12	46%	7.93	60%	10.31		58%	6.62	75%	8.52
	1960 - 1970	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
	Post 60's	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
	Split Level	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
	Split Entry	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
	Up - Down Duplex	6 in 12	48%	8.2	58%	10.01		59%	6.71	71%	8.15
	Row House	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
	Row House	8 in 12	47%	8.12	60%	10.22		59%	6.69	73%	8.37
	Post 1995	4 in 12	48%	8.25	56%	9.63		59%	6.72	68%	7.83
Halifax											
	Pre War	9 in 12	46%	7.81	59%	9.95		58%	6.57	73%	8.24
	Post War One and Half Storey	12 in 12	45%	7.64	59%	9.95		58%	6.47	74%	8.28
	1960 - 1970	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
	Post 60's	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
	Split Level	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
	Split Entry	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
	Up - Down Duplex	6 in 12	47%	7.95	58%	9.72		59%	6.64	71%	8.03
	Row House	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
	Row House	8 in 12	47%	7.86	59%	9.91		59%	6.6	73%	8.2
	Post 1995	4 in 12	48%	8.02	56%	9.38		59%	6.65	69%	7.73
St. John's											
	Pre War	9 in 12	39%	6.77	49%	8.47		50%	5.76	62%	7.18
	Post War One and Half Storey	12 in 12	38%	6.61	49%	8.46		49%	5.65	62%	7.21
	1960 - 1970	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74
	Post 60's	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74
	Split Level	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74
	Split Entry	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74
	Up - Down Duplex	6 in 12	40%	6.91	48%	8.29		51%	5.85	61%	7
	Row House	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74
	Row House	8 in 12	39%	6.82	49%	8.44		50%	5.79	62%	7.15
	Post 1995	4 in 12	40%	6.97	46%	8.01		51%	5.88	58%	6.74

Solar DHW System Costing

In discussions with the solar water heater installation industry the following rules of thumb for pricing for installed systems have been derived for the systems analyzed. Prices include controls, pumps, piping and tank.

Flat Plate Collector Systems				$ / m^2	Total System Cost
6	m^2 collector system w/	240	liter tank	$1,200.00	$7,200.00
12	m^2 collector system w/	480	liter tank	$1,100.00	$13,200.00
18	m^2 collector system w/	720	liter tank	$1,000.00	$18,000.00
24	m^2 collector system w/	960	liter tank	$900.00	$21,600.00
27	m^2 collector system w/	1080	liter tank	$900.00	$24,300.00
30	m^2 collector system w/	1200	liter tank	$800.00	$24,000.00
33	m^2 collector system w/	1320	liter tank	$800.00	$26,400.00
36	m^2 collector system w/	1440	liter tank	$800.00	$28,800.00
39	m^2 collector system w/	1560	liter tank	$800.00	$31,200.00
42	m^2 collector system w/	1680	liter tank	$800.00	$33,600.00

Evacuated Tube Collector Systems				$ / m^2	Total System Cost
6	m^2 collector system w/	480	liter tank	$2,600.00	$15,600.00
12	m^2 collector system w/	960	liter tank	$2,600.00	$31,200.00
18	m^2 collector system w/	1440	liter tank	$2,400.00	$43,200.00
24	m^2 collector system w/	1920	liter tank	$2,200.00	$52,800.00
27	m^2 collector system w/	2160	liter tank	$2,000.00	$54,000.00
30	m^2 collector system w/	2400	liter tank	$1,800.00	$54,000.00
33	m^2 collector system w/	2640	liter tank	$1,800.00	$59,400.00
36	m^2 collector system w/	2880	liter tank	$1,800.00	$64,800.00
39	m^2 collector system w/	3120	liter tank	$1,800.00	$70,200.00
42	m^2 collector system w/	3360	liter tank	$1,800.00	$75,600.00

Economic Viability of Solar DHW Systems

Using the cost analysis and financial summary tabs in RETScreen the economic viability of solar domestic water heating systems was analyzed for the most typical type of system that would be installed consisting of 6m^2 of flat plate solar collector with 240 liters of storage. Analysis was carried out for 15 locations with collector slopes of 4 in 12 (18.5^o) and 12 in 12 (45^o) and hot water consumption of 225 liters per day and 150 liters per day. Roof slopes of 4 in 12 and 12 in 12 represent the typical lowest and slope and steepest slope for roofs in the existing Canadian housing stock.

6 m^2 flat plate solar collector array with 240 liter storage tank hot water supplied at 55°C south facing 4 in 12 slope

City	Solar Water Heating System Type	Total System Cost	Eco Energy Grant	Net Cost to Purchaser	Conventional Fuel Displaced	Conventional Fuels Cost / GJ	Fuel Cost Inflation Rate	Discount Rate	150 Liters / Day Consumption Years to Positive Cash Flow	225 Liters / Day Consumption Years to Positive Cash Flow
Vancouver	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$8.50	10%	10%	20.6	18.3
Whitehorse	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$26.74	10%	10%	10.6	9.2
Calgary	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$4.73	10%	10%	22.7	20.3
Edmonton	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$4.73	10%	10%	23	20.7
Saskatoon	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$7.00	10%	10%	16.9	14.6
Winnipeg	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$7.76	10%	10%	18.6	16.4
Yellowknife	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$24.66	10%	10%	10.8	9.1
Toronto	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$10.70	10%	10%	20.1	17.9
Ottawa	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$10.70	10%	10%	20.2	18.1
Montreal	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Electricity	$19.53	10%	10%	11.8	10.3
Quebec	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Electricity	$19.53	10%	10%	11.1	9.6
Fredricton	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	11.1	9.7
Charlottetown	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	11.1	9.7
Halifax	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	11.2	9.9
St. John's	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$22.07	10%	10%	12.2	10.9

6 m^2 flat plate solar collector array with 240 liter storage tank hot water supplied at 55^{o}C south facing 12 in 12 slope

City	Solar Water Heating System Type	Total System Cost	Eco Energy Grant	Net Cost to Purchaser	Conventional Fuel Displaced	Conventional Fuels Cost / GJ	Fuel Cost Inflation Rate	Discount Rate	150 Liters / Day Consumption Years to Positive Cash Flow	225 Liters / Day Consumption Years to Positive Cash Flow
Vancouver	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$8.50	10%	10%	20	18
Whitehorse	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$26.74	10%	10%	9.8	8.6
Calgary	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$4.73	10%	10%	21.4	19.2
Edmonton	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$4.73	10%	10%	21.5	19.4
Saskatoon	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$7.00	10%	10%	15.7	13.5
Winnipeg	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$7.76	10%	10%	17.5	15.5
Yellowknife	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$24.66	10%	10%	9.9	8.4
Toronto	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$10.70	10%	10%	19.4	17.4
Ottawa	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Gas	$10.70	10%	10%	19.4	16.92
Montreal	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Electricity	$19.53	10%	10%	11.2	9.9
Quebec	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Electricity	$19.53	10%	10%	10.4	9.1
Fredricton	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	10.5	9.3
Charlottetown	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	10.5	9.3
Halifax	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$20.77	10%	10%	10.7	9.5
St. John's	6 m^2 Flate Plate Collector	$7,200	$1,800	$5,400	Oil	$22.07	10%	10%	11.7	10.6

Appendix F: Utilization of Photovoltaic Arrays

An important component of net zero housing is the use of grid connected PV arrays mounted on the roof or wall of the home and/or on an auxiliary building. By sizing the PV array to generate as much electrical power on an annual basis as the house consumes and using the electrical grid in effect as a battery net zero electrical energy consumption can be attained.

Due to the current costs of PV systems it is necessary to minimize the electrical load of the house. For the purposes of this analysis an annual electrical energy budget was used based on that developed for the NZEHH Pilot Demonstration Initiative (now called EQuilibrium Housing) technical requirements of 8760 kWh/yr. The actual annual electrical energy consumption of course will vary with the efficiency of appliances, number and types of appliances, type of lighting and number of lighting fixtures as well as assumptions about the periods of operation.

Following are the assumed PV system characteristics:

- The PV system is central grid connected
- PV energy absorption rate 100%
- PV module type mono-Si
- Nominal PV efficiency 13%
- Nominal Operating Cell Temperature 45 ^{o}C
- PV temperature coefficient 0.40 % / ^{o}C
- Average inverter efficiency 90%

Using RETScreen ver. P3 the performance of PV systems were analyzed in the cities of Vancouver, Whitehorse, Calgary, Edmonton, Saskatoon, Winnipeg, Yellowknife, Toronto, Montreal, Quebec, Fredericton, Charlottetown, Halifax and Saint Johns. The kW peak (kWp) power ratings and areas for PV arrays were calculated for 12 typical roof slopes (1 in 12 to 12 in 12) and vertical facing 5 orientations of South, Southeast, Southwest, East and West. The arrays were sized according to kWp capacity and area to meet the electrical energy budget of 8760 kWh/yr.

For aesthetic reasons and for simplicity of construction it is desirable although not necessary to mount the PV array on the same slope as the roof. Where the roofing tile incorporates the PV cells the PV array slope will be that of the roof. Another consideration is shading of the PV array due to adjacent buildings and vegetation and coverage of the PV array by snow. A low sloping PV array is less likely to be shaded by adjacent buildings and vegetation but is more likely to be covered in snow. One reference[27] found in Minnesota that measured PV power production was reduced by 70% in the winter for an array sloped at 23^{o} and that a 40% reduction in power production was measured for an array in the same location sloped at 40^{o}. Vertical arrays were assumed to be unaffected by snow cover. No credit was given to vertical arrays for reflection from ground snow cover. To gain an understanding of the minimum (kWp) capacity of the PV arrays the basic analysis that was carried out assuming that the arrays are unshaded and not affected by snow cover.

To get a rough approximation of the effect of snow on PV arrays calculations for Calgary and Halifax were also run in which solar radiation levels for November, December, January and February were set at the following.

- For slopes from 1 in12 (4^{o}) to 6 in 12 (26.5^{o}) solar radiation was assumed to be reduced by 70%
- For slopes from 7 in12 (30.5^{o}) to 8 in12 (33.75^{o}) solar radiation was assumed to be reduced by 55%
- For slopes from 9 in12 (37^{o}) to 12 in12 (45^{o}) solar radiation was assumed to be reduced by 40%

For Calgary, a sunny continental climate the kWp capacity required for south facing roof mounted PV arrays increased between 12 and 18%. The kWp capacity of East and West facing roof mounted PV arrays increased between 12 and 16%. The kWp capacity of SE and SW facing roof mounted PV arrays increased between 12 and 16%.

For Halifax, a colder maritime climate the kWp capacity required for south facing roof mounted PV arrays to meet the annual electrical energy budget of 8760 kWh increased between 14 and 17%. The kWp capacity of

[27] PV Watts Changing System Parameters: http://rredc.nrel.gov/solar/codes_algs/PVWATTS/system.html viewed July 12, 2007

East and West facing roof mounted PV arrays increased between 8 and 13%. The kWp capacity of SE and SW facing roof mounted PV arrays increased between 12 and 16%.

So it would appear for all climates except Vancouver that kWp capacities (or areas) of PV arrays except for vertical arrays should be increased in the range of 12 to 18% to compensate for snow cover in winter.

The calculations assume a PV array configuration that would allow the array to shed the snow off the end of the roof. If the array is located in a way in which snow can accumulate or drift over the array, array areas would have to be larger.The results of the RETScreen runs for various slopes and orientations of PV arrays are contained in Appendix G and are summarized below. These will represent minimum values and do not account for snow cover or shading.

Vancouver

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.77 to 9.77 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slopes of 7 in 12 to 9 in 12 (30.5 to 37 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	58m^2 (644 ft^2) to 75.2 m^2 (809 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 11.07 kWp 85.2m^2 (917 ft^2) East / West 13.47 kWp 103.6 m^2 (1115 ft^2) SE / SW 11.4 kWp 87.7 m^2 (944 ft^2)

Whitehorse

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.82 to 10.68 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slopes of 12 in 12 (45 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	60.2m^2 (648 ft^2) to 82.2 m^2 (884.8 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.36 kWp 72m^2 (775 ft^2) East / West 13.23 kWp 101.8 m^2 (1096 ft^2) SE / SW 10.18 kWp 78.3 m^2 (843 ft^2)

Calgary

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	5.75 to 8.07 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 12 in 12 (45 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	44.2m^2 (476 ft^2) to 62.1 m^2 (668 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 6.99 kWp 53.8m^2 (579 ft^2) East / West 10.19 kWp 78.4 m^2 (844 ft^2) SE / SW 7.69 kWp 59.2 m^2 (637 ft^2)

Edmonton

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	5.88 to 8.37 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 12 in 12 (45 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	45m^2 (484 ft^2) to 64.4 m^2 (668 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 6.92 kWp 53.2m^2 (573 ft^2) East / West 10.31 kWp 79.3 m^2 (854 ft^2) SE / SW 7.66 kWp 58.9 m^2 (634 ft^2)

Winnipeg

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	6.12 to 8.29 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 12 in 12 (45 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	47.1m^2 (505 ft^2) to 63.8 m^2 (687 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 7.57 kWp 58.2m^2 (626 ft^2) East / West 10.42 kWp 80.2 m^2 (863 ft^2) SE / SW 8.16 kWp 62.8 m^2 (676 ft^2)

Yellowknife

Roof Mounted PV array range of capacities to meet 8760	7.82 to 10.68 kWp

kWh/yr	
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 12 in 12 (45 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	60.2 m^2 (648 ft^2) to 82.2 m^2 (885 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.36 kWp 72m^2 (775 ft^2) East / West 13.22 kWp 101.7 m^2 (1095 ft^2) SE / SW 10.18 kWp 78.3 m^2 (843 ft^2)

Toronto

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.20 to 8.99 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 7 in 12 (30.5 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	55.4m^2 (596 ft^2) to 69.2 m^2 (745 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 10.18 kWp 78.3m^2 (843 ft^2) East / West 12.23 kWp 94.1 m^2 (1013 ft^2) SE / SW 10.46 kWp 80.5 m^2 (867 ft^2)

Ottawa

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.10 to 8.86 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 9 in 12 (37 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	53.2m^2 (588 ft^2) to 68.2 m^2 (734 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.2 kWp 70.8m^2 (762 ft^2) East / West 11.7 kWp 90 m^2 (969 ft^2) SE / SW 9.67 kWp 74.4 m^2 (801 ft^2)

Montreal

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.10 to 9.02 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 9 in 12 (37 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	54.6m^2 (588 ft^2) to 68.2 m^2 (734 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.45 kWp 72.7m^2 (783 ft^2) East / West 12.06 kWp 92.8 m^2 (999 ft^2) SE / SW 9.96 kWp 76.6 m^2 (825 ft^2)

Quebec

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	6.43 to 8.55 kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 11 in 12 (42.5 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	49.5m^2 (533 ft^2) to 65.8 m^2 (708ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 8.15 kWp 62.7m^2 (675 ft^2) East / West 10.98 kWp 84.5 m^2 (910 ft^2) SE / SW 8.55 kWp 65.8 m^2 (708 ft^2)

Fredericton

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.02 to 9.12kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 11 in 12 (42.5 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	54m^2 (581 ft^2) to 70.2 m^2 (761 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.19 kWp 70.7m^2 (675 ft^2) East / West 12.05 kWp 92.7 m^2 (998 ft^2) SE / SW 9.77 kWp 75.2 m^2 (809 ft^2)

Charlottetown

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	6.98 to 9.03kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 10 in 12 (40 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	53.7m^2 (578 ft^2) to 69.5 m^2 (778 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.15 kWp 70.4m^2 (758 ft^2) East / West 10.5 kWp 80.8 m^2 (870 ft^2) SE / SW 9.68 kWp 74.5 m^2 (802 ft^2)

Halifax

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	7.18 to 9.24kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 10 in 12 (40 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45^{o})
For 13% efficient mono-Si panels the array areas ranges	55.2m^2 (594 ft^2) to 71.1 m^2 (765 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.49 kWp 73m^2 (786 ft^2) East / West 12.32 kWp 94.8m^2 (1020 ft^2) SE / SW 10.07 kWp 77.5 m^2 (834 ft^2)

St. John's

Roof Mounted PV array range of capacities to meet 8760 kWh/yr	8.23 to 10.45kWp
Lowest PV array capacity to meet 8760 kWh/yr	South facing roof slope of 9 in 12 (37 degrees)
Highest PV array capacity to meet 8760 kWh/yr	East / West facing roofs with slopes of 12 in 12 (45 ^{o})
For 13% efficient mono-Si panels the array areas ranges	63.3 (681 ft^2) to 80.4 m^2 (865 ft^2)
Wall mounted array capacities and areas for 13% efficient mono-Si panels	South 9.49 kWp 73m^2 (786 ft^2) East / West 12.32 kWp 94.8m^2 (1020 ft^2) SE / SW 11.05 kWp 85 m^2 (915 ft^2)

Potential for Power Generation by PV's in the Existing Housing Stock

The following tables summarize the range of sizes of grid connected PV arrays needed for solar energy to supply an annual electricity requirement of 8760 kWh for typical existing housing types across Canada assuming the collectors are mounted on the roof at the existing roof slope. The PV arrays are sized for roofs facing East or West and South. The effect of snow cover on PV array size is also estimated based on the approach described previously. In the cases where the array areas would prove too large for the roof areas available the following strategies could be taken:

Reduce electrical loads further through use of more efficient appliances and lighting

Place all appliances that have parasitic loads on power bars that are only switched on when the appliance is used.

Use roofs of auxiliary buildings such as garages for mounting a portion of the PV array

Use deck covers and porch roofs to support PV arrays.

Use power-cost monitors to give occupants real time information on electrical consumption to encourage demand side load management

Photovoltaic Array kWp capacity and area to meet 8760 kWh/ yr

Location	Age / Description	Typical Roof Slope	East / West						South					
			Without Snow Cover			With Snow Cover Over Winter			Without Snow Cover			With Snow Cover Over Winter		
			Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power
Vancouver			m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp
	Pre War	9 in 12	72.6	781	9.44	72.6	781	9.44	59.8	644	7.77	59.8	644	7.77
	Post War One and Half Storey	12 in 12	75.2	809	9.77	75.2	809	9.77	60.6	652	7.88	60.6	652	7.88
	1960 - 1970	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
	Post 60's	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
	Split Level	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
	Split Entry	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
	Up - Down Duplex	6 in 12	70	753	9.10	70	753	9.10	60	646	7.80	60.0	646	7.80
	Row House	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
	Row House	8 in 12	71.7	772	9.32	71.7	772	9.32	59.8	644	7.77	59.8	644	7.77
	Post 1995	4 in 12	68.5	737	8.90	68.5	737	8.90	60.9	656	7.92	60.9	656	7.92
Whitehorse														
	Pre War	9 in 12	80.8	870	10.50	89.3	961	11.61	60.9	656	7.92	70.0	754	9.10
	Post War One and Half Storey	12 in 12	82.2	885	10.68	90.8	978	11.81	60.2	648	7.82	69.2	745	9.00
	1960 - 1970	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
	Post 60's	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
	Split Level	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
	Split Entry	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
	Up - Down Duplex	6 in 12	79.5	856	10.33	87.8	946	11.42	63.1	679	8.20	72.6	781	9.43
	Row House	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
	Row House	8 in 12	80.5	867	10.46	89.0	958	11.56	61.4	661	7.98	70.6	760	9.18
	Post 1995	4 in 12	78.7	847	10.23	87.0	936	11.30	65.8	708	8.55	75.7	815	9.84
Clagary														
	Pre War	9 in 12	60.8	654	7.90	70.5	759	9.17	44.8	482	5.82	52.9	569	6.87
	Post War One and Half Storey	12 in 12	62.1	668	8.07	72.0	775	9.36	44.2	476	5.75	52.2	561	6.78
	1960 - 1970	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42
	Post 60's	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42
	Split Level	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42
	Split Entry	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42
	Up - Down Duplex	6 in 12	59.3	638	7.71	68.8	740	8.94	46.4	499	6.03	54.8	589	7.12
	Row House	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42
	Row House	8 in 12	60.2	648	7.82	69.8	752	9.08	45.2	487	5.88	53.3	574	6.93
	Post 1995	4 in 12	58.5	630	7.60	67.9	730	8.82	48.4	521	6.29	57.1	615	7.42

Photovoltaic Array kWp capacity and area to meet 8760 kWh/ yr

Location	Age / Description	Typical Roof Slope	East / West						South					
			Without Snow Cover			With Snow Cover Over Winter			Without Snow Cover			With Snow Cover Over Winter		
			Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power
Edmonton			m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp
	Pre War	9 in 12	63.2	680	8.21	73.3	789	9.53	45.8	493	5.95	54.0	582	7.02
	Post War One and Half Storey	12 in 12	64.4	693	8.37	74.7	804	9.71	45.2	487	5.88	53.3	574	6.93
	1960 - 1970	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
	Post 60's	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
	Split Level	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
	Split Entry	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
	Up - Down Duplex	6 in 12	62.1	668	8.07	72.0	775	9.36	47.8	515	6.21	56.4	607	7.33
	Row House	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
	Row House	8 in 12	62.8	676	8.16	72.8	784	9.47	46.4	499	6.03	54.8	589	7.12
	Post 1995	4 in 12	61.3	660	7.97	71.1	765	9.24	50.2	540	6.53	59.2	638	7.70
Saskatoon														
	Pre War	9 in 12	58.5	630	7.60	67.9	730	8.82	42.5	457	5.52	50.2	540	6.52
	Post War One and Half Storey	12 in 12	59.6	642	7.75	69.1	744	8.99	41.8	450	5.43	49.3	531	6.41
	1960 - 1970	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
	Post 60's	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
	Split Level	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
	Split Entry	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
	Up - Down Duplex	6 in 12	57.4	618	7.46	66.6	717	8.65	44.2	476	5.75	52.2	561	6.78
	Row House	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
	Row House	8 in 12	58.1	625	7.55	67.4	725	8.76	42.9	462	5.58	50.6	545	6.58
	Post 1995	4 in 12	56.7	610	7.37	65.8	708	8.55	46.5	501	6.04	54.9	591	7.13
Winnipeg														
	Pre War	9 in 12	62.4	672	8.11	72.4	779	9.41	47.4	510	6.16	55.9	602	7.27
	Post War One and Half Storey	12 in 12	63.8	687	8.29	74.0	797	9.62	47.1	507	6.12	55.6	598	7.22
	1960 - 1970	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76
	Post 60's	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76
	Split Level	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76
	Split Entry	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76
	Up - Down Duplex	6 in 12	60.8	654	7.90	70.5	759	9.17	48.8	525	6.34	57.6	620	7.48
	Row House	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76
	Row House	8 in 12	61.8	665	8.03	71.7	772	9.32	47.8	515	6.21	56.4	607	7.33
	Post 1995	4 in 12	59.9	645	7.79	69.5	748	9.03	50.6	545	6.58	59.7	643	7.76

Photovoltaic Array kWp capacity and area to meet 8760 kWh/ yr

Location	Age / Description	Typical Roof Slope	East / West						South					
			Without Snow Cover			With Snow Cover Over Winter			Without Snow Cover			With Snow Cover Over Winter		
			Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power
Yellowknife			m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp
	Pre War	9 in 12	80.8	870	10.50	90.5	974	11.76	60.9	656	7.92	69.4	747	9.02
	Post War One and Half Storey	12 in 12	82.2	885	10.68	92.1	991	11.97	60.2	648	7.82	68.6	739	8.92
	1960 - 1970	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
	Post 60's	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
	Split Level	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
	Split Entry	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
	Up - Down Duplex	6 in 12	79.5	856	10.33	89.0	958	11.57	63.1	679	8.20	71.9	774	9.35
	Row House	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
	Row House	8 in 12	80.5	867	10.46	90.2	971	11.72	61.4	661	7.98	70.0	753	9.10
	Post 1995	4 in 12	78.7	847	10.23	88.1	949	11.46	65.8	708	8.55	75.0	807	9.75
Toronto														
	Pre War	9 in 12	66.8	719	8.68	74.8	805	9.72	55.5	597	7.21	63.3	681	8.22
	Post War One and Half Storey	12 in 12	69.2	745	8.99	77.5	834	10.07	56.2	605	7.31	64.1	690	8.33
	1960 - 1970	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
	Post 60's	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
	Split Level	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
	Split Entry	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
	Up - Down Duplex	6 in 12	64.4	693	8.37	72.1	776	9.38	55.5	597	7.21	63.3	681	8.22
	Row House	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
	Row House	8 in 12	66	710	8.58	73.9	796	9.61	55.4	596	7.20	63.2	680	8.21
	Post 1995	4 in 12	62.9	677	8.18	70.4	758	9.16	56.3	606	7.32	64.2	691	8.34
Ottawa														
	Pre War	9 in 12	66	710	8.58	73.9	796	9.61	53.2	573	6.92	60.6	653	7.88
	Post War One and Half Storey	12 in 12	68.2	734	8.86	76.4	822	9.93	53.5	576	6.95	61.0	657	7.93
	1960 - 1970	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14
	Post 60's	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14
	Split Level	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14
	Split Entry	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14
	Up - Down Duplex	6 in 12	63.8	687	8.29	71.5	769	9.29	53.8	579	6.99	61.3	660	7.97
	Row House	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14
	Row House	8 in 12		0	0.00	0.0	0	0.00	53.2	573	6.92	60.6	653	7.88
	Post 1995	4 in 12	62.5	673	8.12	70.0	753	9.10	54.9	591	7.14	62.6	674	8.14

Photovoltaic Array kWp capacity and area to meet 8760 kWh/ yr

Location	Age / Description	Typical Roof Slope	East / West						South					
			Without Snow Cover			With Snow Cover Over Winter			Without Snow Cover			With Snow Cover Over Winter		
			Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power
Montreal			m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp
	Pre War	9 in 12	67.8	730	8.81	75.9	817	9.87	54.6	588	7.10	62.2	670	8.09
	Post War One and Half Storey	12 in 12	70.1	755	9.11	78.5	845	10.21	54.9	591	7.14	62.6	674	8.14
	1960 - 1970	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
	Post 60's	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
	Split Level	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
	Split Entry	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
	Up - Down Duplex	6 in 12	65.6	706	8.53	73.5	791	9.55	55.2	594	7.18	62.9	677	8.18
	Row House	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
	Row House	8 in 12	67.1	722	8.72	75.2	809	9.77	54.7	589	7.11	62.4	671	8.11
	Post 1995	4 in 12	64.2	691	8.34	71.9	774	9.35	56.5	608	7.34	64.4	693	8.37
Quebec														
	Pre War	9 in 12	64	689	8.32	71.7	772	9.32	49.7	535	6.46	56.7	610	7.36
	Post War One and Half Storey	12 in 12	65.8	708	8.55	73.7	793	9.58	49.6	534	6.45	56.5	609	7.35
	1960 - 1970	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
	Post 60's	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
	Split Level	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
	Split Entry	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
	Up - Down Duplex	6 in 12	62.2	670	8.08	69.7	750	9.06	50.8	547	6.60	57.9	623	7.53
	Row House	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
	Row House	8 in 12	63.5	684	8.25	71.1	766	9.24	49.9	537	6.49	56.9	612	7.39
	Post 1995	4 in 12	61.1	658	7.94	68.4	737	8.89	52.4	564	6.81	59.7	643	7.76
Fredricton														
	Pre War	9 in 12	68.1	733	8.85	75.3	810	9.78	54	581	7.02	62.1	668	8.07
	Post War One and Half Storey	12 in 12	70.2	756	9.12	77.6	835	10.08	54.2	583	7.05	62.3	671	8.10
	1960 - 1970	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40
	Post 60's	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40
	Split Level	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40
	Split Entry	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40
	Up - Down Duplex	6 in 12	65.8	708	8.55	72.7	783	9.45	54.8	590	7.12	63.0	678	8.19
	Row House	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40
	Row House	8 in 12	67.3	724	8.75	74.4	801	9.67	54.2	583	7.05	62.3	671	8.10
	Post 1995	4 in 12	64.5	694	8.38	71.3	767	9.26	56.2	605	7.31	64.6	696	8.40

Photovoltaic Array kWp capacity and area to meet 8760 kWh/ yr

Location	Age / Description	Typical Roof Slope	East / West						South					
			Without Snow Cover			With Snow Cover Over Winter			Without Snow Cover			With Snow Cover Over Winter		
			Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power	Estimated Collector Area Required		Nominal PV Array Power
Charlottetown			m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp	m^2	ft^2	kWp
	Pre War	9 in 12	67.4	726	8.76	74.5	802	9.68	53.7	578	6.98	61.8	665	8.03
	Post War One and Half Storey	12 in 12	69.5	748	9.03	76.8	827	9.98	53.8	579	6.99	61.9	666	8.04
	1960 - 1970	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
	Post 60's	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
	Split Level	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
	Split Entry	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
	Up - Down Duplex	6 in 12	65.2	702	8.47	72.0	776	9.36	54.5	587	7.08	62.7	675	8.15
	Row House	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
	Row House	8 in 12	66.6	717	8.66	73.6	792	9.57	53.8	579	6.99	61.9	666	8.04
	Post 1995	4 in 12	63.9	688	8.31	70.6	760	9.18	55.8	601	7.25	64.2	691	8.34
Halifax														
	Pre War	9 in 12	68.6	738	8.92	75.8	816	9.85	55.2	594	7.18	63.5	683	8.25
	Post War One and Half Storey	12 in 12	71.1	765	9.24	78.6	846	10.21	55.4	596	7.20	63.7	686	8.28
	1960 - 1970	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
	Post 60's	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
	Split Level	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
	Split Entry	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
	Up - Down Duplex	6 in 12	66.5	716	8.64	73.5	791	9.55	55.6	598	7.23	63.9	688	8.31
	Row House	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
	Row House	8 in 12	68	732	8.84	75.1	809	9.77	55.2	594	7.18	63.5	683	8.25
	Post 1995	4 in 12	65.2	702	8.47	72.0	776	9.36	57.1	615	7.42	65.7	707	8.54
St. John's														
	Pre War	9 in 12	77.7	836	10.10	85.9	924	11.16	63.3	681	8.23	72.8	784	9.46
	Post War One and Half Storey	12 in 12	80.4	865	10.45	88.8	956	11.55	63.8	687	8.29	73.4	790	9.54
	1960 - 1970	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72
	Post 60's	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72
	Split Level	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72
	Split Entry	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72
	Up - Down Duplex	6 in 12	75	807	9.75	82.9	892	10.77	63.8	687	8.29	73.4	790	9.54
	Row House	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72
	Row House	8 in 12	76.8	827	9.98	84.9	913	11.03	63.3	681	8.23	72.8	784	9.46
	Post 1995	4 in 12	73.4	790	9.54	81.1	873	10.54	65	700	8.45	74.8	805	9.72

General Conclusions

For the roof slopes calculated using RETScreen the optimum south facing roof slope to provide the 8760 kWh/yr varies between 7 in 12 (30.5 degrees) and 12 and 12 (45 degrees). Steeper slope are better suited to climates with more clear winter days and the lower slope are better suited to climates with cloudier winter weather because the summer solar radiation contributes a larger percentage of the annual PV electrical power supply.

Vertical south facing PV arrays are more effective the further north the building is located this is due to the lower sun angles experienced at northerly latitudes. The required areas for vertical PV arrays are always larger than those required for sloped arrays. The power produced from a vertical PV array will be affected by the reflectivity of the horizontal surfaces to the south of the array so actual power production would have to be analyzed on a case by case basis.

For optimum roof slopes the PV array areas for the 13% efficient mono-Si panels range from 44 to 63m^2 (475 to 680ft^2). An additional 12 to 18% increase in PV array areas will likely be needed to compensate for periods of snow cover.

These roof areas could occur on homes with foot prints of in the range of 93 m^2 to 150 m^2 (1000 to 1600 ft^2). Although many more homes will have appropriate roof areas for PV arrays when the areas required for the arrays are reduced. At this time (2007) the maximum conversion efficiency from solar radiation into electricity for mass produced PV's is in the range of 13 to 16.5 %. As further R&D is carried out into PV technologies efficiencies will increase and costs decrease. It is conceivable in a decade that mass produced PV efficiencies could be double what they are today cutting the roof areas required by PV's in half (refer to fig 1 below).

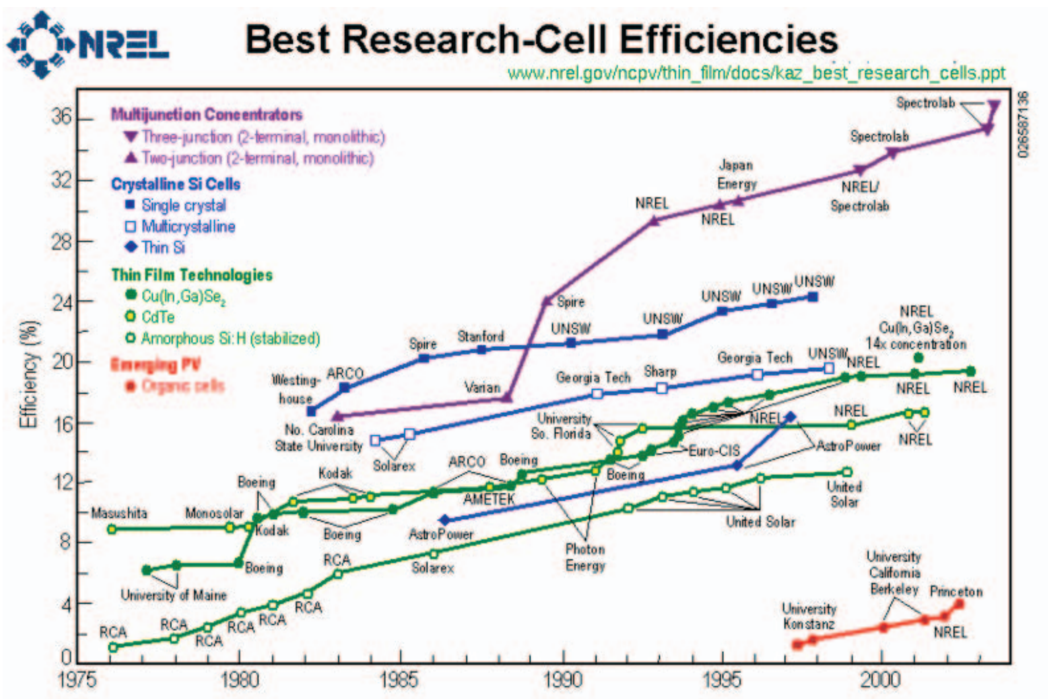


Figure 1: Best research photovoltaic cell efficiencies as of 2003

Characteristics of Photovoltaic Arrays to meet Annual Electrical Energy Budget of 8760 kWh

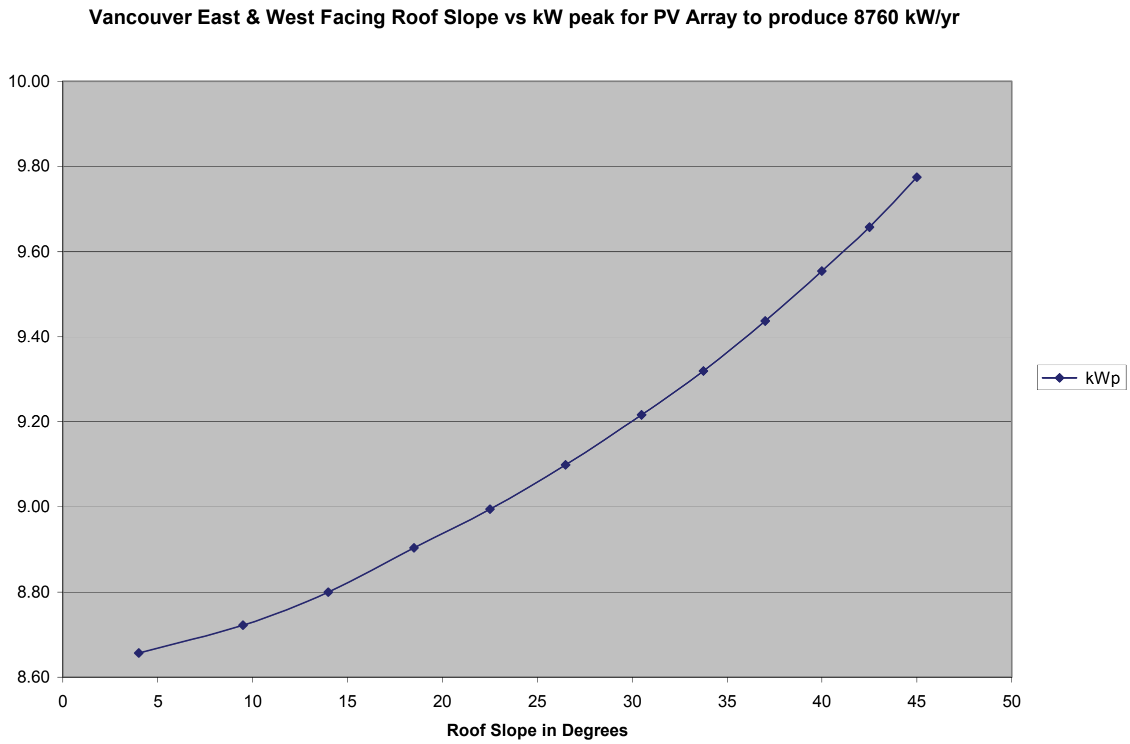
Vancouver

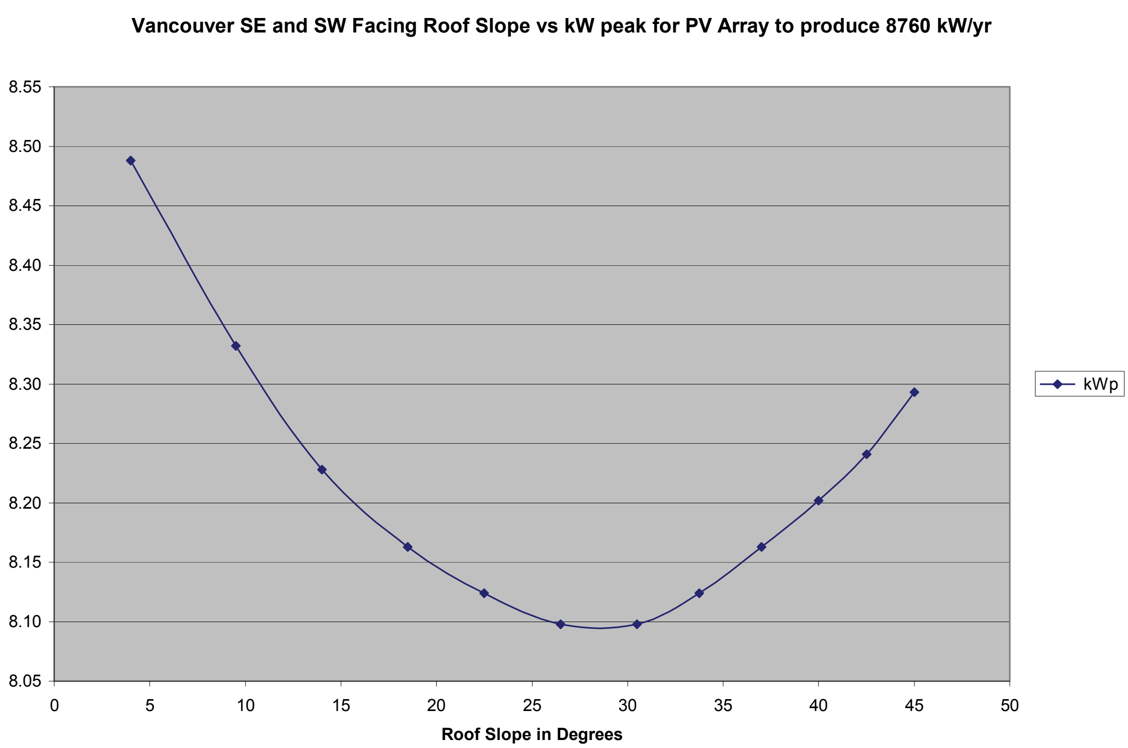
Annual power production of 8760 kWh/yr — Grid connected system mono-Si 13% efficiency

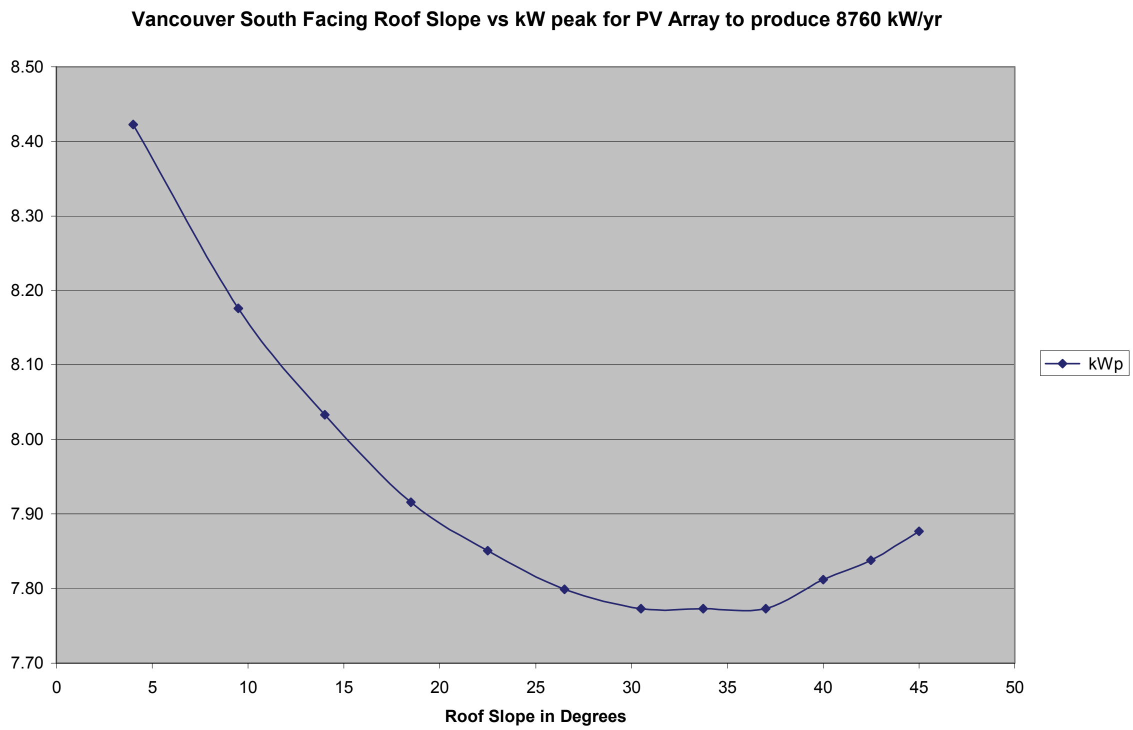
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	66.6	717	8.66
	2 in 12	9.5	67.1	722	8.72
	3 in 12	14	67.7	729	8.80
	4 in 12	18.5	68.5	737	8.90
	5 in 12	22.5	69.2	745	8.99
	6 in 12	26.5	70	753	9.10
	7 in 12	30.5	70.9	763	9.22
	8 in 12	33.75	71.7	772	9.32
	9 in 12	37	72.6	781	9.44
	10 in 12	40	73.5	791	9.55
	11 in 12	42.5	74.3	800	9.66
	12 in 12	45	75.2	809	9.77
	Vertical Wall	90	103.6	1115	13.47

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	65.3	703	8.49
	2 in 12	9.5	64.1	690	8.33
	3 in 12	14	63.3	681	8.23
	4 in 12	18.5	62.8	676	8.16
	5 in 12	22.5	62.5	673	8.12
	6 in 12	26.5	62.3	671	8.10
	7 in 12	30.5	62.3	671	8.10
	8 in 12	33.75	62.5	673	8.12
	9 in 12	37	62.8	676	8.16
	10 in 12	40	63.1	679	8.20
	11 in 12	42.5	63.4	682	8.24
	12 in 12	45	63.8	687	8.29
	Vertical Wall	90	87.7	944	11.40

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	64.8	698	8.42
	2 in 12	9.5	62.9	677	8.18
	3 in 12	14	61.8	665	8.03
	4 in 12	18.5	60.9	656	7.92
	5 in 12	22.5	60.4	650	7.85
	6 in 12	26.5	60	646	7.80
	7 in 12	30.5	59.8	644	7.77
	8 in 12	33.75	59.8	644	7.77
	9 in 12	37	59.8	644	7.77
	10 in 12	40	60.1	647	7.81
	11 in 12	42.5	60.3	649	7.84
	12 in 12	45	60.6	652	7.88
	Vertical Wall	90	85.2	917	11.07


Vancouver East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
10.00
9.80
9.60
9.40
9.20
9.00
8.80
8.60
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Vancouver SE and SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.55
8.50
8.45
8.40
8.35
8.30
8.25
8.20
8.15
8.10
8.05
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp



Vancouver South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.50
8.40
8.30
8.20
8.10
8.00
7.90
7.80
7.70
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

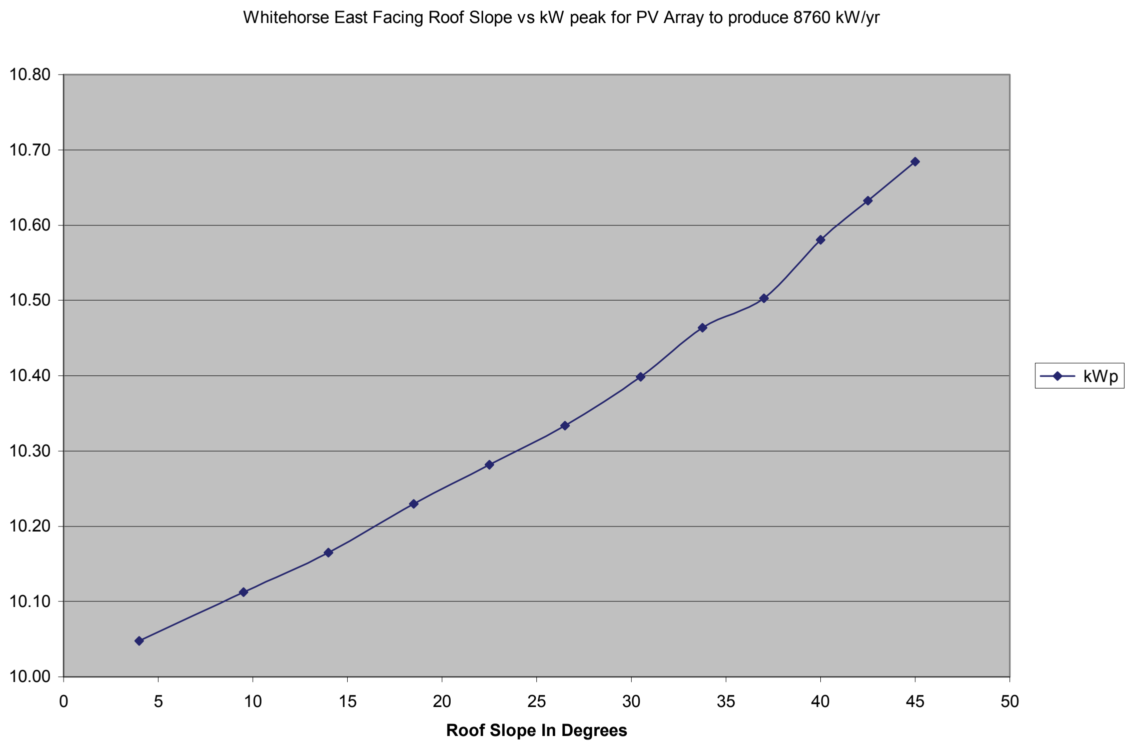
Whitehorse

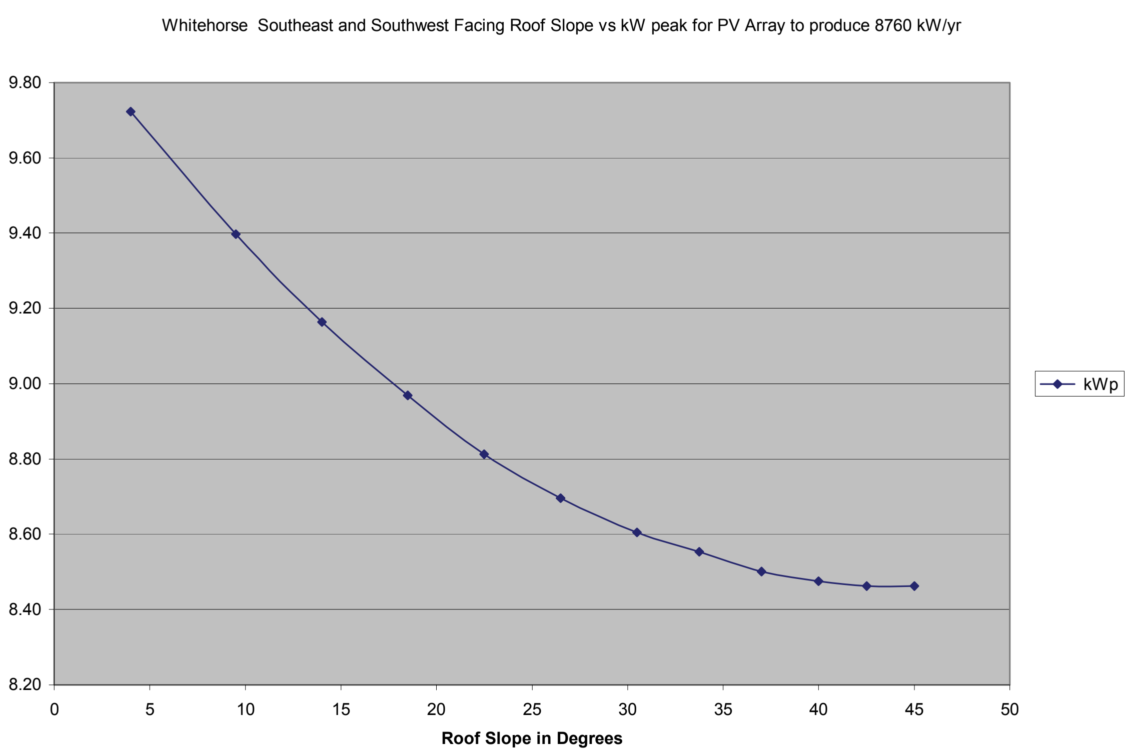
Annual power production of 8760 kWh/yr — Grid connected system mono-Si 13% efficiency

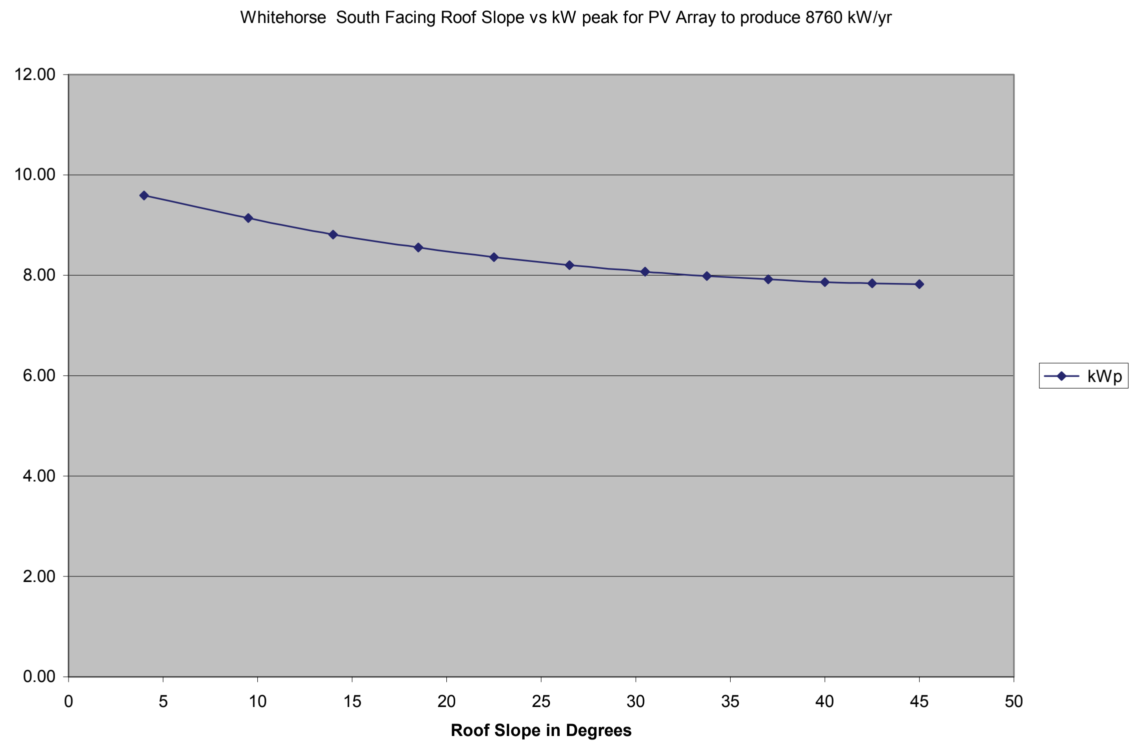
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	77.3	832	10.05
	2 in 12	9.5	77.8	837	10.11
	3 in 12	14	78.2	842	10.16
	4 in 12	18.5	78.7	847	10.23
	5 in 12	22.5	79.1	851	10.28
	6 in 12	26.5	79.5	856	10.33
	7 in 12	30.5	80	861	10.40
	8 in 12	33.75	80.5	867	10.46
	9 in 12	37	80.8	870	10.50
	10 in 12	40	81.4	876	10.58
	11 in 12	42.5	81.8	881	10.63
	12 in 12	45	82.2	885	10.68
	Vertical wall	90	101.8	1096	13.23

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	74.8	805	9.72
	2 in 12	9.5	72.3	778	9.40
	3 in 12	14	70.5	759	9.16
	4 in 12	18.5	69	743	8.97
	5 in 12	22.5	67.8	730	8.81
	6 in 12	26.5	66.9	720	8.70
	7 in 12	30.5	66.2	713	8.60
	8 in 12	33.75	65.8	708	8.55
	9 in 12	37	65.4	704	8.50
	10 in 12	40	65.2	702	8.47
	11 in 12	42.5	65.1	701	8.46
	12 in 12	45	65.1	701	8.46
	Vertical wall	90	78.3	843	10.18

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	73.8	794	9.59
	2 in 12	9.5	70.3	757	9.14
	3 in 12	14	67.8	730	8.81
	4 in 12	18.5	65.8	708	8.55
	5 in 12	22.5	64.3	692	8.36
	6 in 12	26.5	63.1	679	8.20
	7 in 12	30.5	62.1	668	8.07
	8 in 12	33.75	61.4	661	7.98
	9 in 12	37	60.9	656	7.92
	10 in 12	40	60.5	651	7.86
	11 in 12	42.5	60.3	649	7.84
	12 in 12	45	60.2	648	7.82
	Vertical wall	90	72	775	9.36


Whitehorse East Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
10.80
10.70
10.60
10.50
10.40
10.30
10.20
10.10
10.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope In Degrees
kWp


Whitehorse Southeast and Southwest Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.80
9.60
9.40
9.20
9.00
8.80
8.60
8.40
8.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp



Whitehorse South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

Calgary

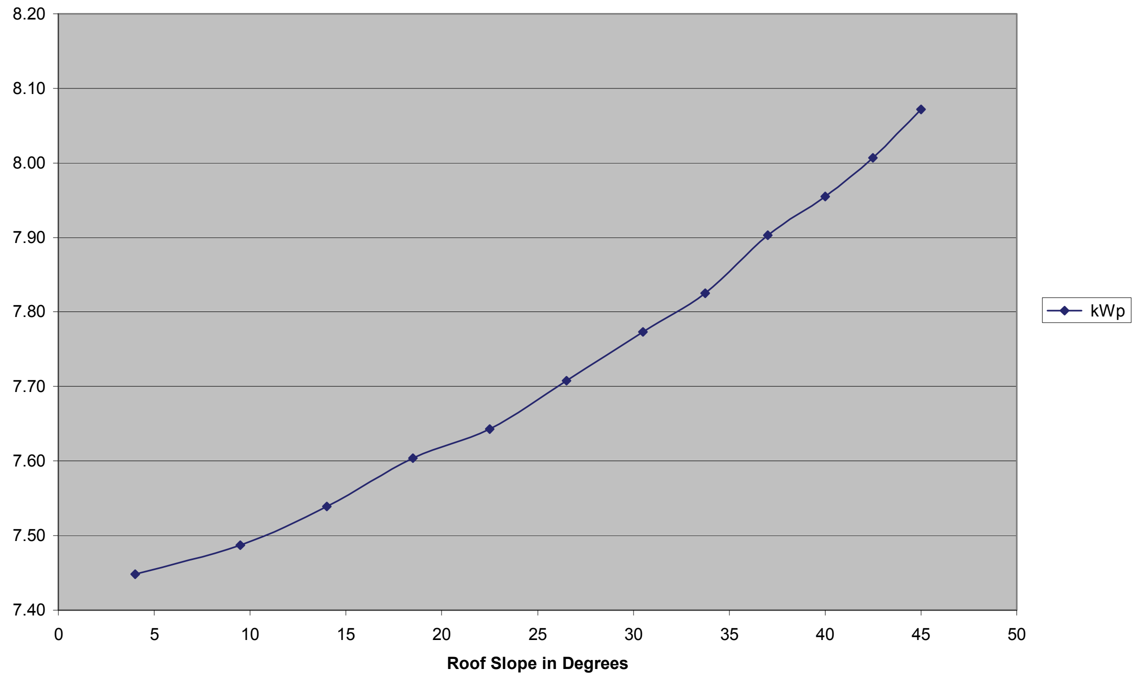
Annual power production of 8760 kWh/yr   Grid connected system mono-Si 13% efficiency

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
East / West	1 in 12	4	57.3	617	7.45
	2 in 12	9.5	57.6	620	7.49
	3 in 12	14	58	624	7.54
	4 in 12	18.5	58.5	630	7.60
	5 in 12	22.5	58.8	633	7.64
	6 in 12	26.5	59.3	638	7.71
	7 in 12	30.5	59.8	644	7.77
	8 in 12	33.75	60.2	648	7.82
	9 in 12	37	60.8	654	7.90
	10 in 12	40	61.2	659	7.95
	11 in 12	42.5	61.6	663	8.01
	12 in 12	45	62.1	668	8.07
	Vertical Wall	90	78.4	844	10.19

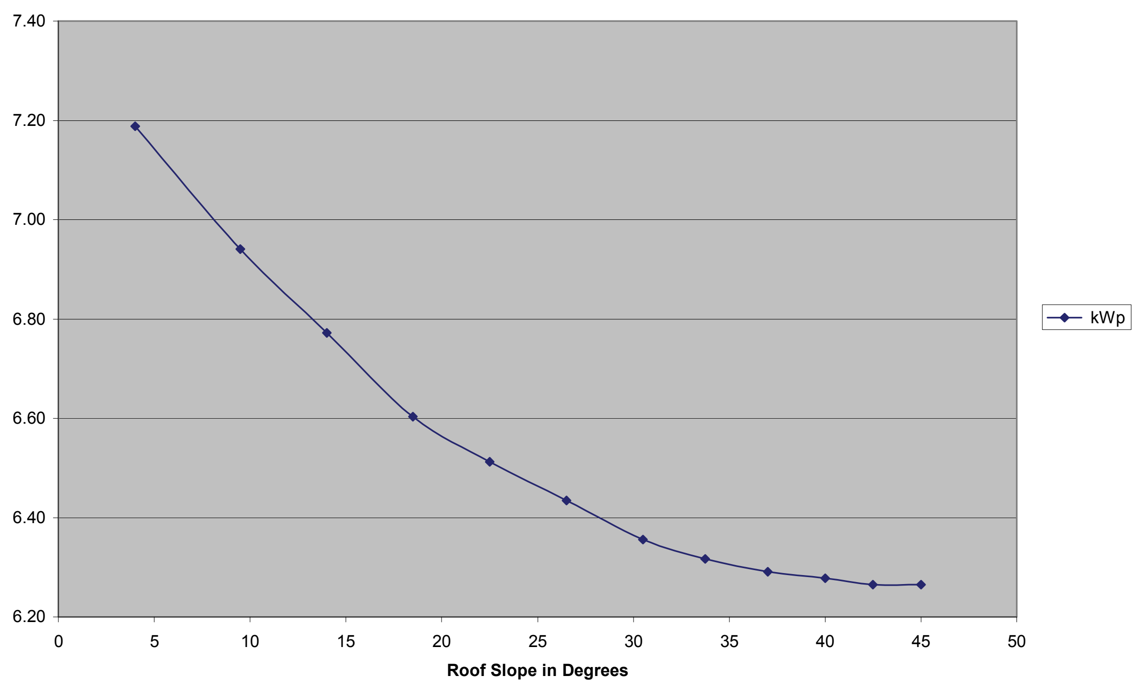
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
Southeast / Southwest	1 in 12	4	55.3	595	7.19
	2 in 12	9.5	53.4	575	6.94
	3 in 12	14	52.1	561	6.77
	4 in 12	18.5	50.8	547	6.60
	5 in 12	22.5	50.1	539	6.51
	6 in 12	26.5	49.5	533	6.43
	7 in 12	30.5	48.9	526	6.36
	8 in 12	33.75	48.6	523	6.32
	9 in 12	37	48.4	521	6.29
	10 in 12	40	48.3	520	6.28
	11 in 12	42.5	48.2	519	6.27
	12 in 12	45	48.2	519	6.27
	Vertical Wall	90	59.2	637	7.69

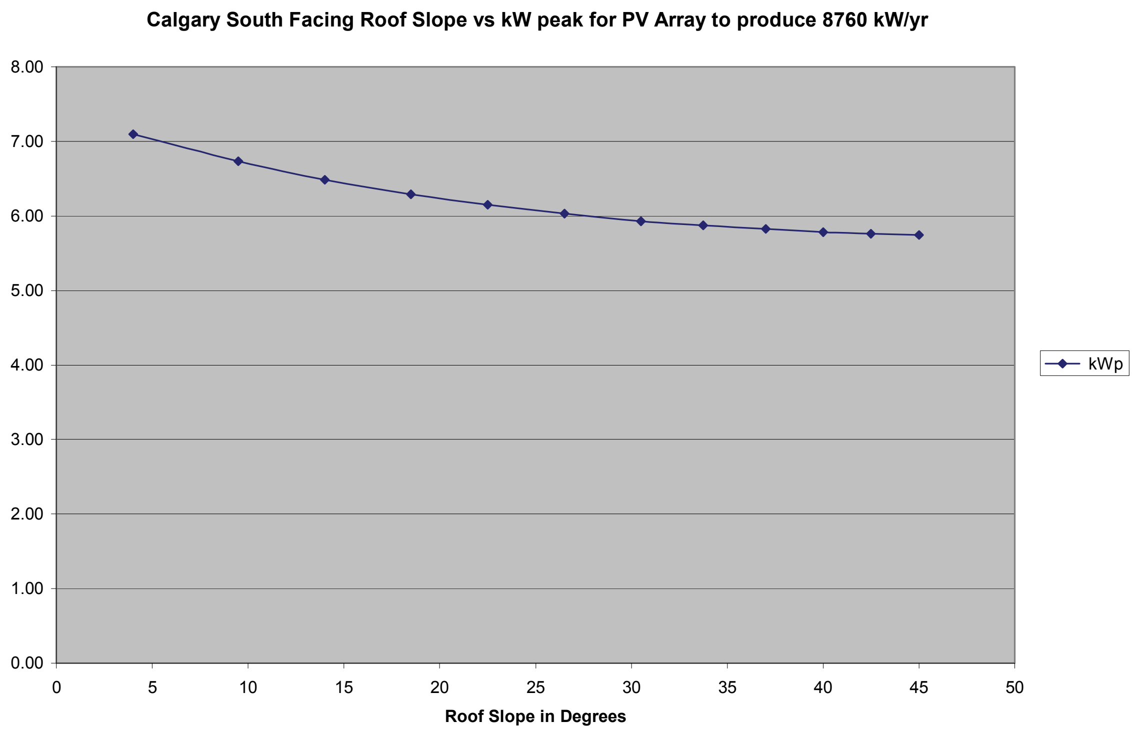
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
South	1 in 12	4	54.6	588	7.10
	2 in 12	9.5	51.8	558	6.73
	3 in 12	14	49.9	537	6.49
	4 in 12	18.5	48.4	521	6.29
	5 in 12	22.5	47.3	509	6.15
	6 in 12	26.5	46.4	499	6.03
	7 in 12	30.5	45.6	491	5.93
	8 in 12	33.75	45.2	487	5.88
	9 in 12	37	44.8	482	5.82
	10 in 12	40	44.5	479	5.78
	11 in 12	42.5	44.3	477	5.76
	12 in 12	45	44.2	476	5.75
	Vertical Wall	90	53.8	579	6.99

Calgary East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr



Calgary SE and SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr




Calgary South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

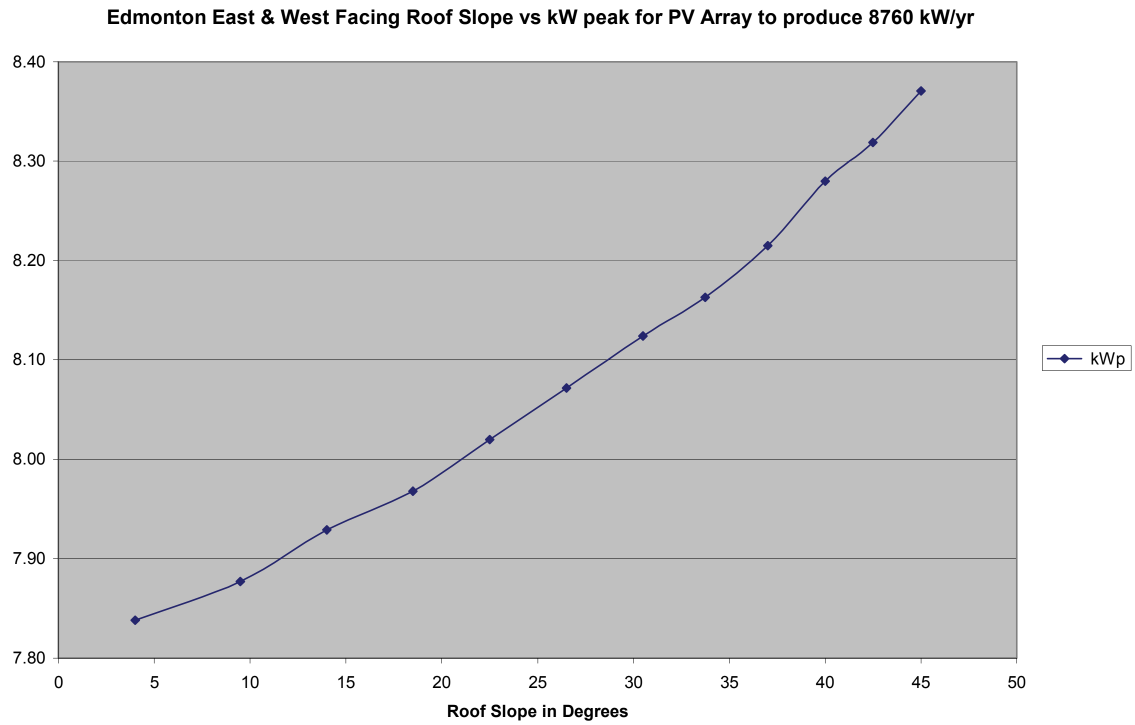
Edmonton

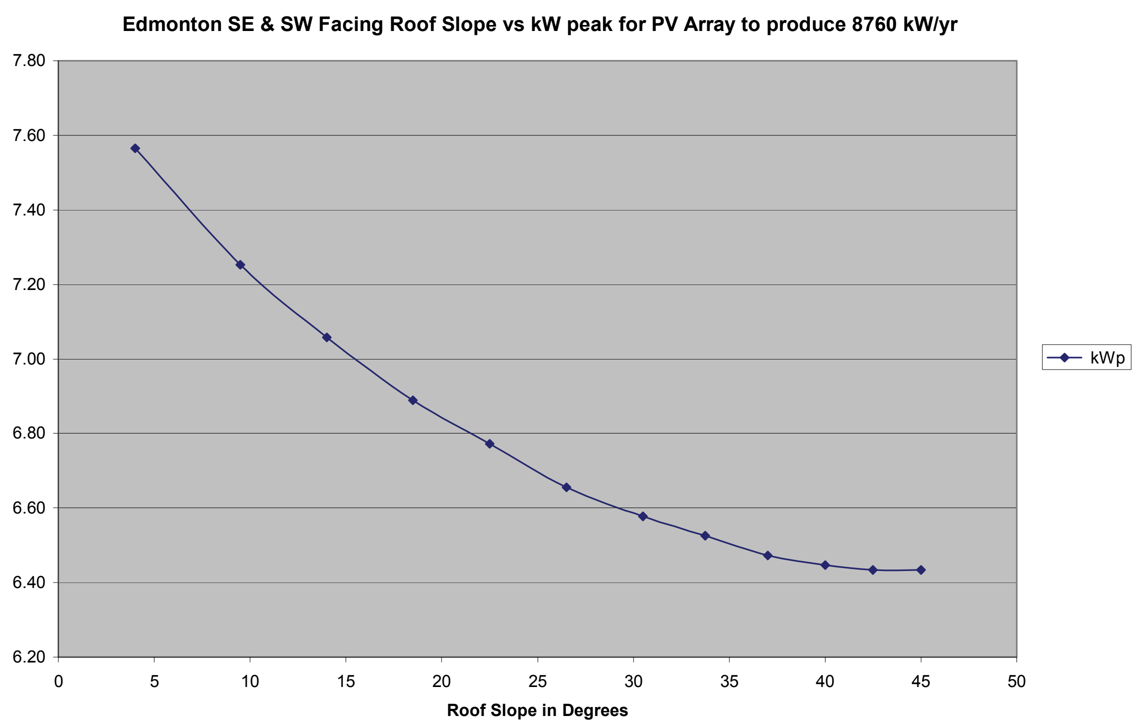
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

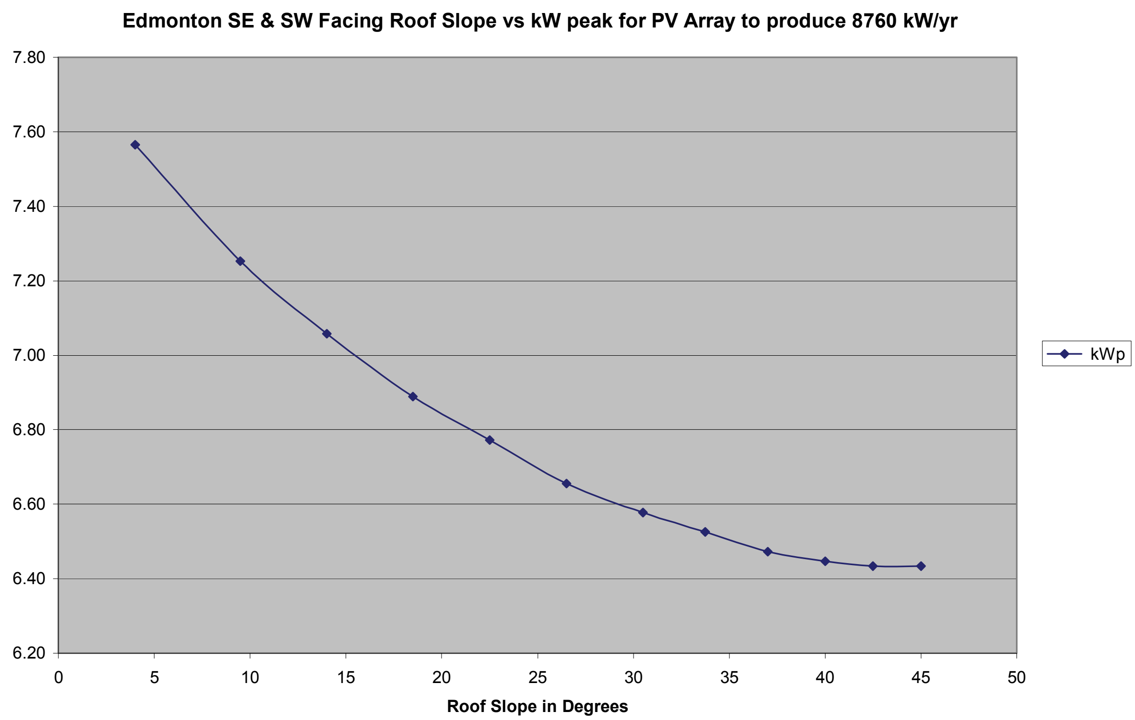
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	60.3	649	7.84
	2 in 12	9.5	60.6	652	7.88
	3 in 12	14	61	657	7.93
	4 in 12	18.5	61.3	660	7.97
	5 in 12	22.5	61.7	664	8.02
	6 in 12	26.5	62.1	668	8.07
	7 in 12	30.5	62.5	673	8.12
	8 in 12	33.75	62.8	676	8.16
	9 in 12	37	63.2	680	8.21
	10 in 12	40	63.7	686	8.28
	11 in 12	42.5	64	689	8.32
	12 in 12	45	64.4	693	8.37
	Vertical Wall	90	79.3	854	10.31

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	58.2	626	7.57
	2 in 12	9.5	55.8	601	7.25
	3 in 12	14	54.3	584	7.06
	4 in 12	18.5	53	571	6.89
	5 in 12	22.5	52.1	561	6.77
	6 in 12	26.5	51.2	551	6.66
	7 in 12	30.5	50.6	545	6.58
	8 in 12	33.75	50.2	540	6.53
	9 in 12	37	49.8	536	6.47
	10 in 12	40	49.6	534	6.45
	11 in 12	42.5	49.5	533	6.43
	12 in 12	45	49.5	533	6.43
	Vertical Wall	90	58.9	634	7.66

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	57.3	617	7.45
	2 in 12	9.5	54.2	583	7.05
	3 in 12	14	52	560	6.76
	4 in 12	18.5	50.2	540	6.53
	5 in 12	22.5	49.1	529	6.38
	6 in 12	26.5	47.8	515	6.21
	7 in 12	30.5	46.9	505	6.10
	8 in 12	33.75	46.4	499	6.03
	9 in 12	37	45.8	493	5.95
	10 in 12	40	45.5	490	5.91
	11 in 12	42.5	45.3	488	5.89
	12 in 12	45	45.2	487	5.88
	Vertical Wall	90	53.2	573	6.92


Edmonton East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.40
8.30
8.20
8.10
8.00
7.90
7.80
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Edmonton SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.80
7.60
7.40
7.20
7.00
6.80
6.60
6.40
6.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

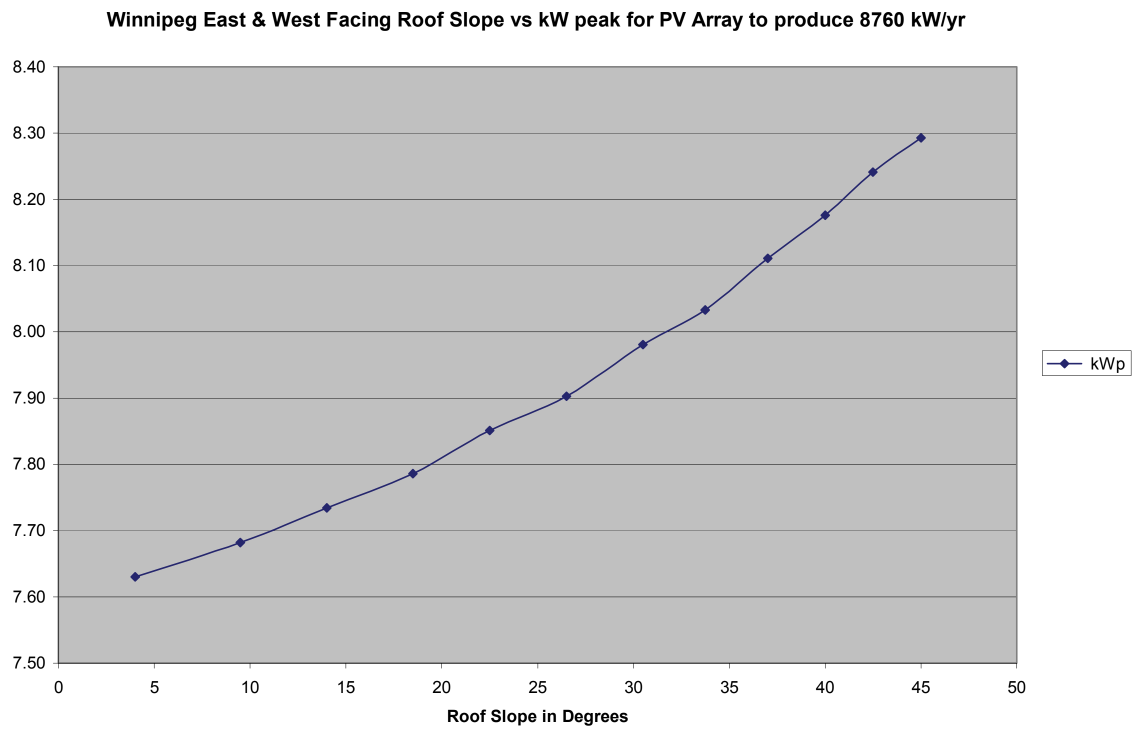

Edmonton SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.80
7.60
7.40
7.20
7.00
6.80
6.60
6.40
6.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

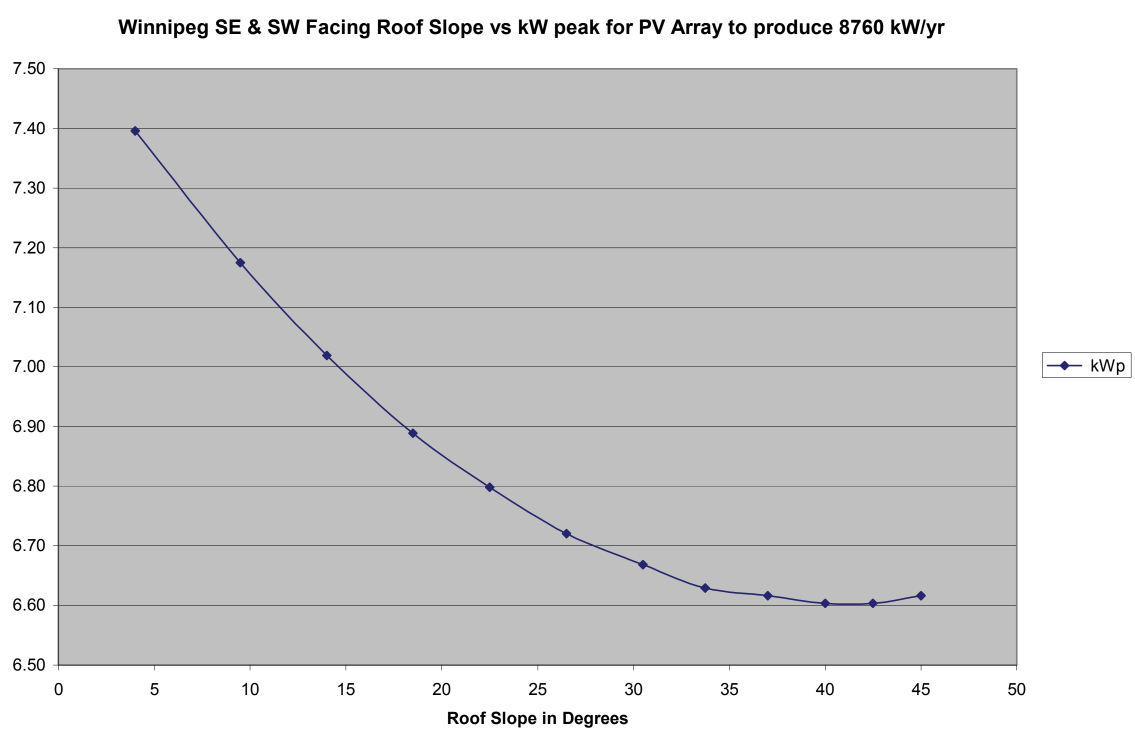
Winnipeg
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

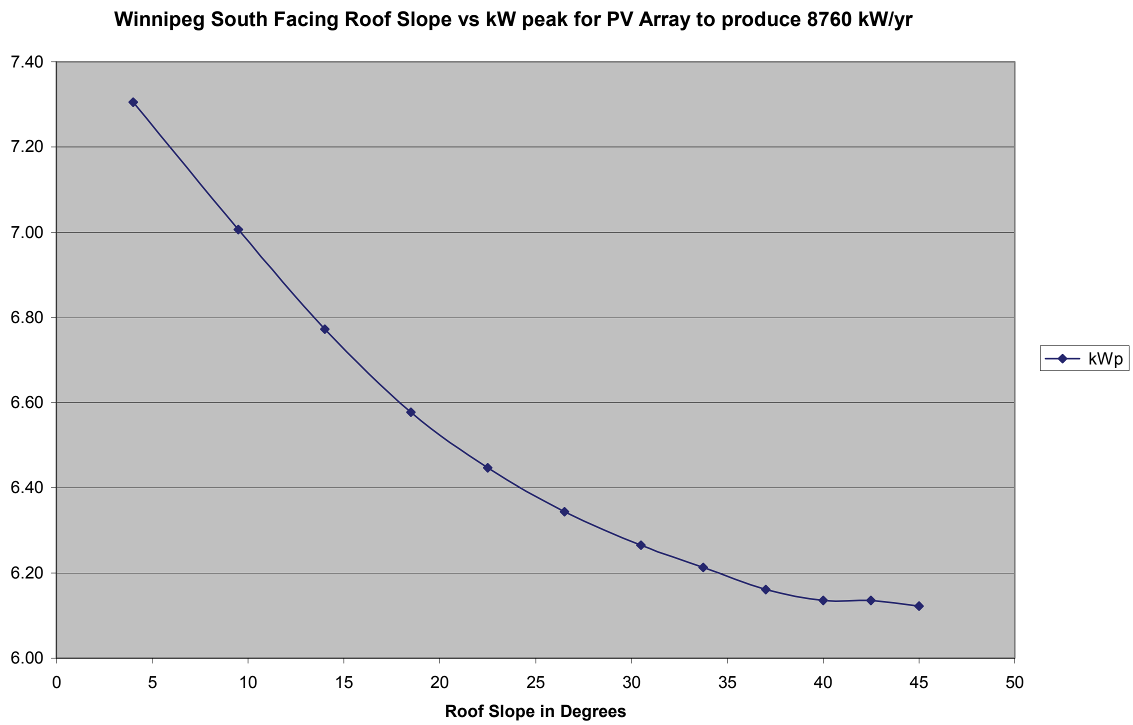
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
East / West	1 in 12	4	58.7	632	7.63
	2 in 12	9.5	59.1	636	7.68
	3 in 12	14	59.5	640	7.73
	4 in 12	18.5	59.9	645	7.79
	5 in 12	22.5	60.4	650	7.85
	6 in 12	26.5	60.8	654	7.90
	7 in 12	30.5	61.4	661	7.98
	8 in 12	33.75	61.8	665	8.03
	9 in 12	37	62.4	672	8.11
	10 in 12	40	62.9	677	8.18
	11 in 12	42.5	63.4	682	8.24
	12 in 12	45	63.8	687	8.29
	Vertical Wall	90	80.2	863	10.42

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
Southeast / Southwest	1 in 12	4	56.9	612	7.40
	2 in 12	9.5	55.2	594	7.18
	3 in 12	14	54	581	7.02
	4 in 12	18.5	53	571	6.89
	5 in 12	22.5	52.3	563	6.80
	6 in 12	26.5	51.7	557	6.72
	7 in 12	30.5	51.3	552	6.67
	8 in 12	33.75	51	549	6.63
	9 in 12	37	50.9	548	6.62
	10 in 12	40	50.8	547	6.60
	11 in 12	42.5	50.8	547	6.60
	12 in 12	45	50.9	548	6.62
	Vertical Wall	90	62.8	676	8.16

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
South	1 in 12	4	56.2	605	7.31
	2 in 12	9.5	53.9	580	7.01
	3 in 12	14	52.1	561	6.77
	4 in 12	18.5	50.6	545	6.58
	5 in 12	22.5	49.6	534	6.45
	6 in 12	26.5	48.8	525	6.34
	7 in 12	30.5	48.2	519	6.27
	8 in 12	33.75	47.8	515	6.21
	9 in 12	37	47.4	510	6.16
	10 in 12	40	47.2	508	6.14
	11 in 12	42.5	47.2	508	6.14
	12 in 12	45	47.1	507	6.12
	Vertical Wall	90	58.2	626	7.57


Winnipeg East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.40
8.30
8.20
8.10
8.00
7.90
7.80
7.70
7.60
7.50
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Winnipeg SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.50
7.40
7.30
7.20
7.10
7.00
6.90
6.80
6.70
6.60
6.50
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Winnipeg South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.40
7.20
7.00
6.80
6.60
6.40
6.20
6.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

Yellowknife

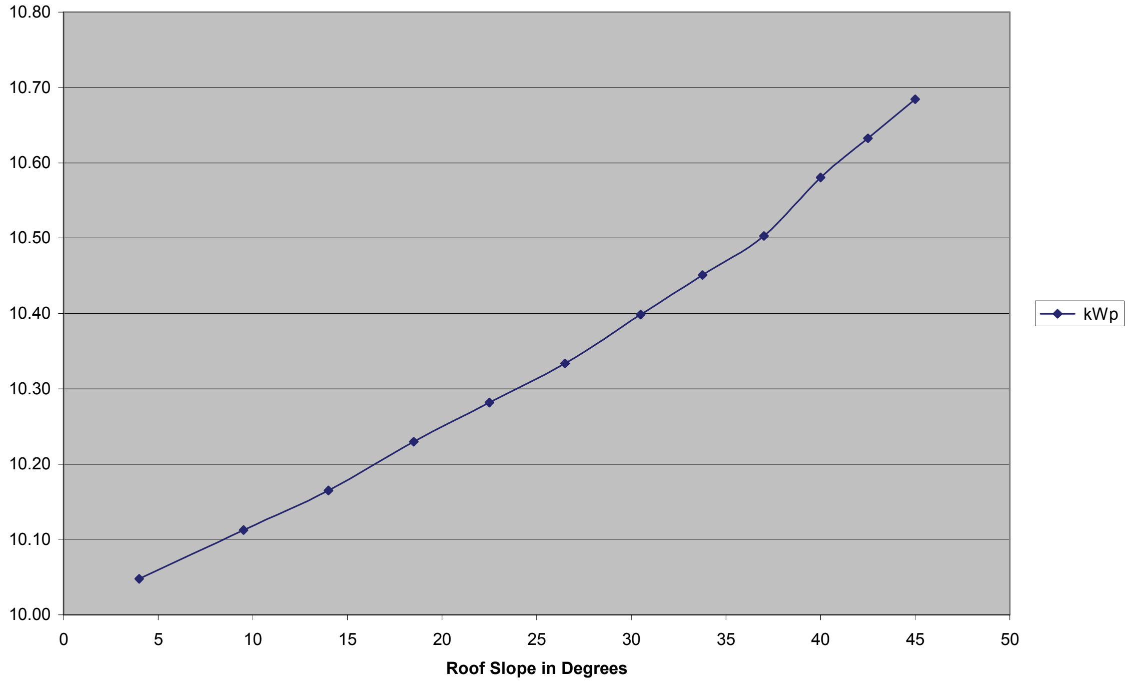
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	77.3	832	10.05
	2 in 12	9.5	77.8	837	10.11
	3 in 12	14	78.2	842	10.16
	4 in 12	18.5	78.7	847	10.23
	5 in 12	22.5	79.1	851	10.28
	6 in 12	26.5	79.5	856	10.33
	7 in 12	30.5	80	861	10.40
	8 in 12	33.75	80.4	865	10.45
	9 in 12	37	80.8	870	10.50
	10 in 12	40	81.4	876	10.58
	11 in 12	42.5	81.8	881	10.63
	12 in 12	45	82.2	885	10.68
	Vertical wall	90	101.7	1095	13.22

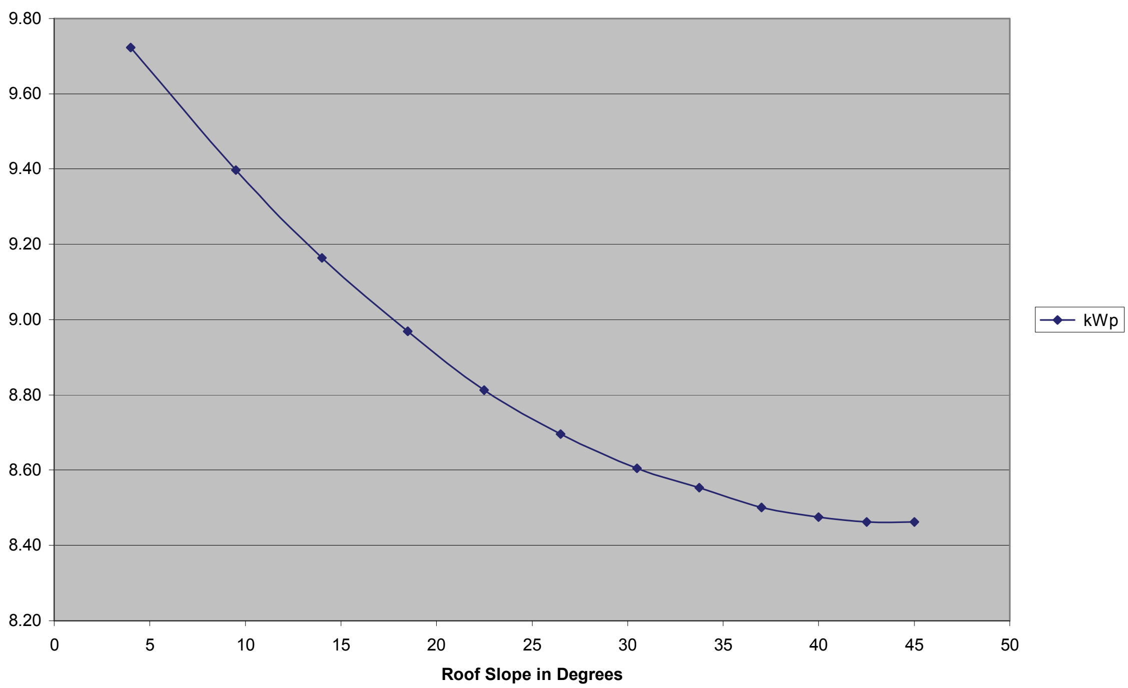
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	74.8	805	9.72
	2 in 12	9.5	72.3	778	9.40
	3 in 12	14	70.5	759	9.16
	4 in 12	18.5	69	743	8.97
	5 in 12	22.5	67.8	730	8.81
	6 in 12	26.5	66.9	720	8.70
	7 in 12	30.5	66.2	713	8.60
	8 in 12	33.75	65.8	708	8.55
	9 in 12	37	65.4	704	8.50
	10 in 12	40	65.2	702	8.47
	11 in 12	42.5	65.1	701	8.46
	12 in 12	45	65.1	701	8.46
	Vertical wall	90	78.3	843	10.18

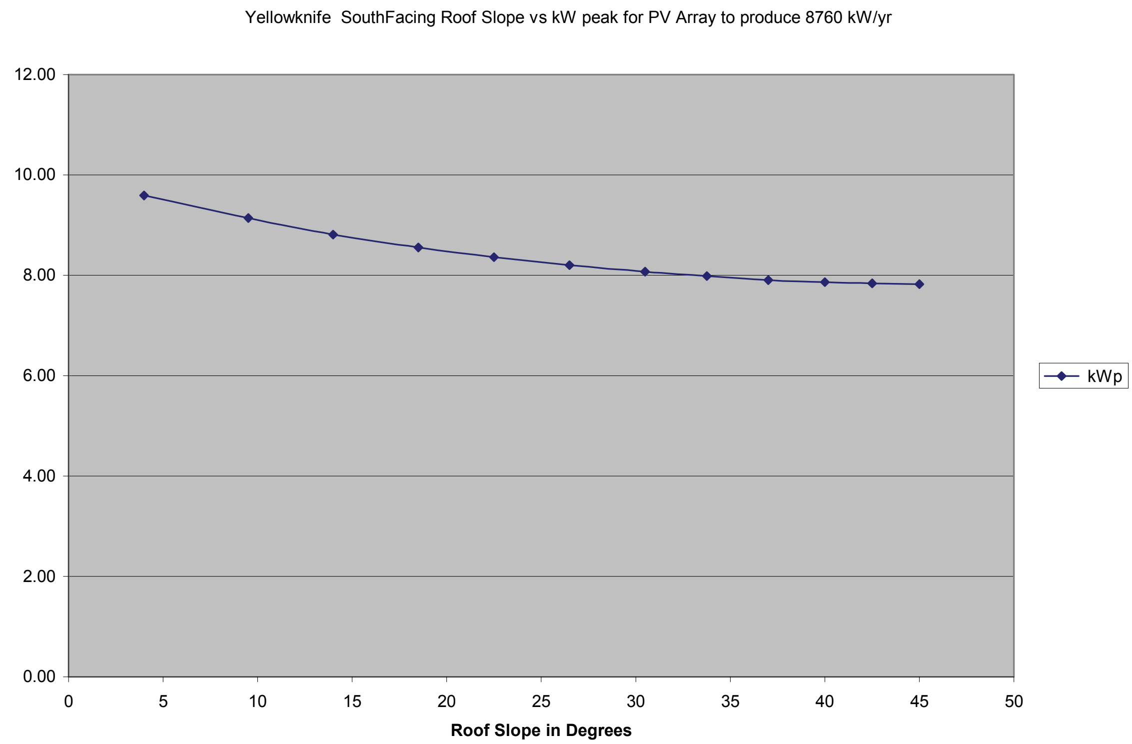
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	73.8	794	9.59
	2 in 12	9.5	70.3	757	9.14
	3 in 12	14	67.8	730	8.81
	4 in 12	18.5	65.8	708	8.55
	5 in 12	22.5	64.3	692	8.36
	6 in 12	26.5	63.1	679	8.20
	7 in 12	30.5	62.1	668	8.07
	8 in 12	33.75	61.4	661	7.98
	9 in 12	37	60.8	654	7.90
	10 in 12	40	60.5	651	7.86
	11 in 12	42.5	60.3	649	7.84
	12 in 12	45	60.2	648	7.82
	Vertical wall	90	72	775	9.36

Yellowknife East / West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr



Yellowknife Southeast and Southwest Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr




Yellowknife SouthFacing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

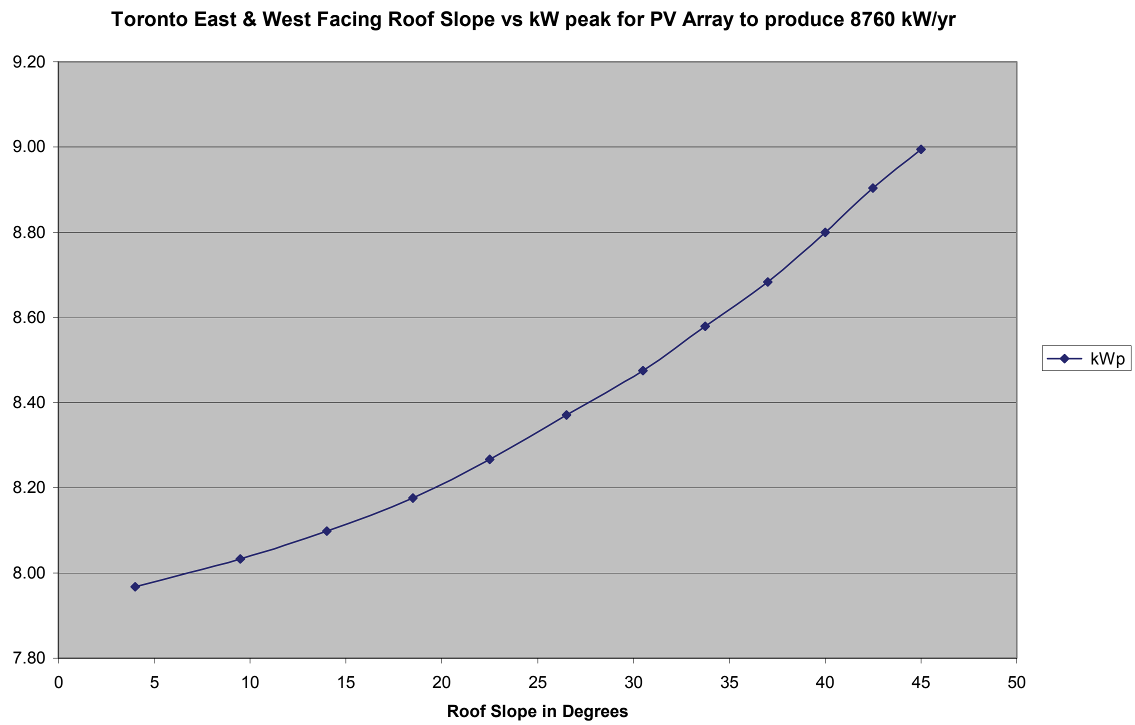
Toronto

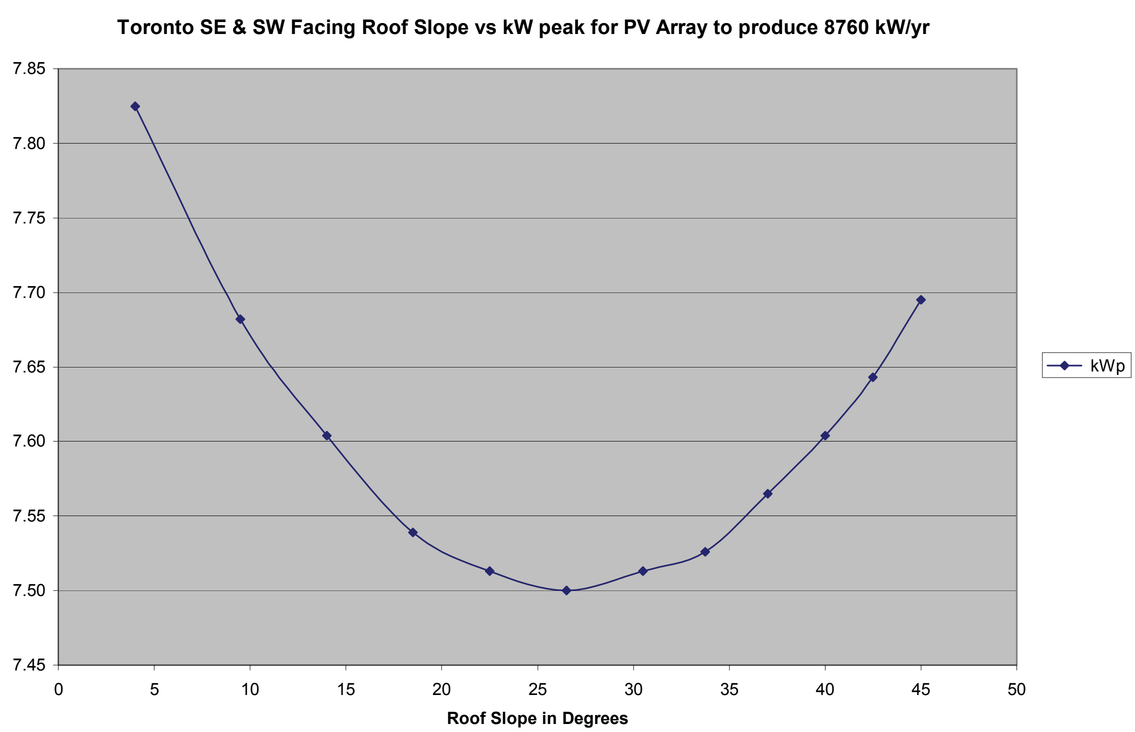
Annual power production of 8760 kWh/yr — Grid connected system mono-Si 13% efficiency

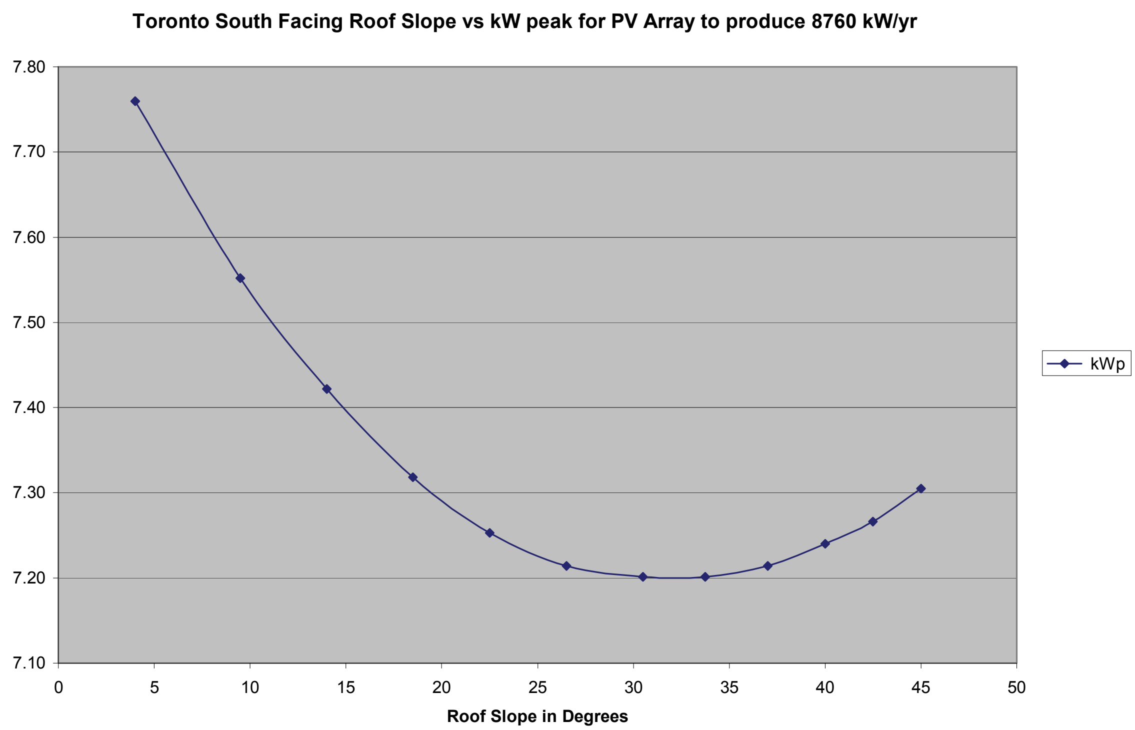
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	61.3	660	7.97
	2 in 12	9.5	61.8	665	8.03
	3 in 12	14	62.3	671	8.10
	4 in 12	18.5	62.9	677	8.18
	5 in 12	22.5	63.6	685	8.27
	6 in 12	26.5	64.4	693	8.37
	7 in 12	30.5	65.2	702	8.47
	8 in 12	33.75	66	710	8.58
	9 in 12	37	66.8	719	8.68
	10 in 12	40	67.7	729	8.80
	11 in 12	42.5	68.5	737	8.90
	12 in 12	45	69.2	745	8.99
	Vertical Wall	90	94.1	1013	12.23

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	60.2	648	7.82
	2 in 12	9.5	59.1	636	7.68
	3 in 12	14	58.5	630	7.60
	4 in 12	18.5	58	624	7.54
	5 in 12	22.5	57.8	622	7.51
	6 in 12	26.5	57.7	621	7.50
	7 in 12	30.5	57.8	622	7.51
	8 in 12	33.75	57.9	623	7.53
	9 in 12	37	58.2	626	7.57
	10 in 12	40	58.5	630	7.60
	11 in 12	42.5	58.8	633	7.64
	12 in 12	45	59.2	637	7.69
	Vertical Wall	90	80.5	867	10.46

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	59.7	643	7.76
	2 in 12	9.5	58.1	625	7.55
	3 in 12	14	57.1	615	7.42
	4 in 12	18.5	56.3	606	7.32
	5 in 12	22.5	55.8	601	7.25
	6 in 12	26.5	55.5	597	7.21
	7 in 12	30.5	55.4	596	7.20
	8 in 12	33.75	55.4	596	7.20
	9 in 12	37	55.5	597	7.21
	10 in 12	40	55.7	600	7.24
	11 in 12	42.5	55.9	602	7.27
	12 in 12	45	56.2	605	7.31
	Vertical Wall	90	78.3	843	10.18


Toronto East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.20
9.00
8.80
8.60
8.40
8.20
8.00
7.80
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Toronto SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.85
7.80
7.75
7.70
7.65
7.60
7.55
7.50
7.45
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Toronto South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

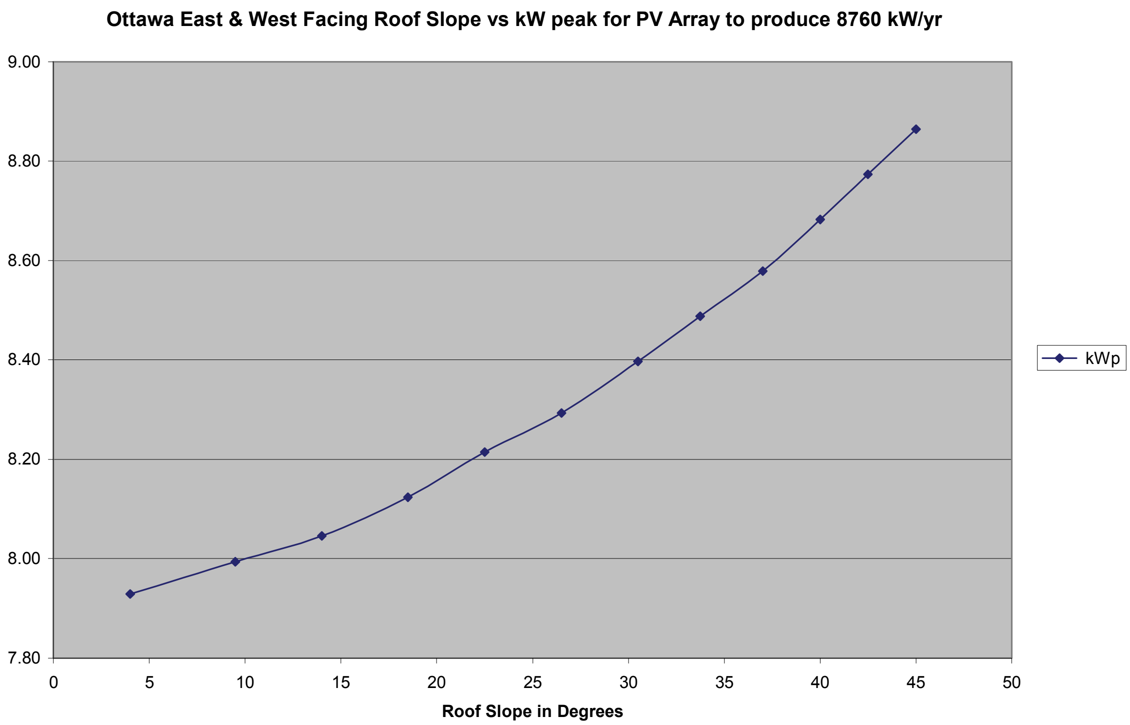
Ottawa

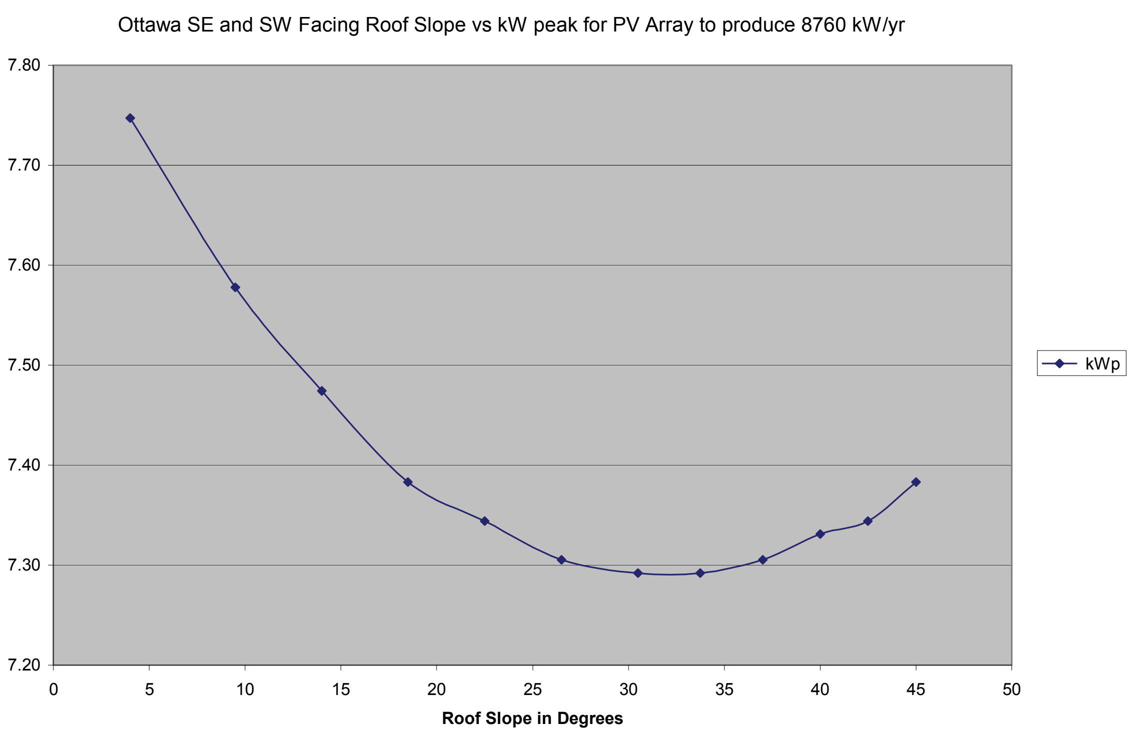
Annual power production of 8760 kWh/yr — Grid connected system mono-Si 13% efficiency

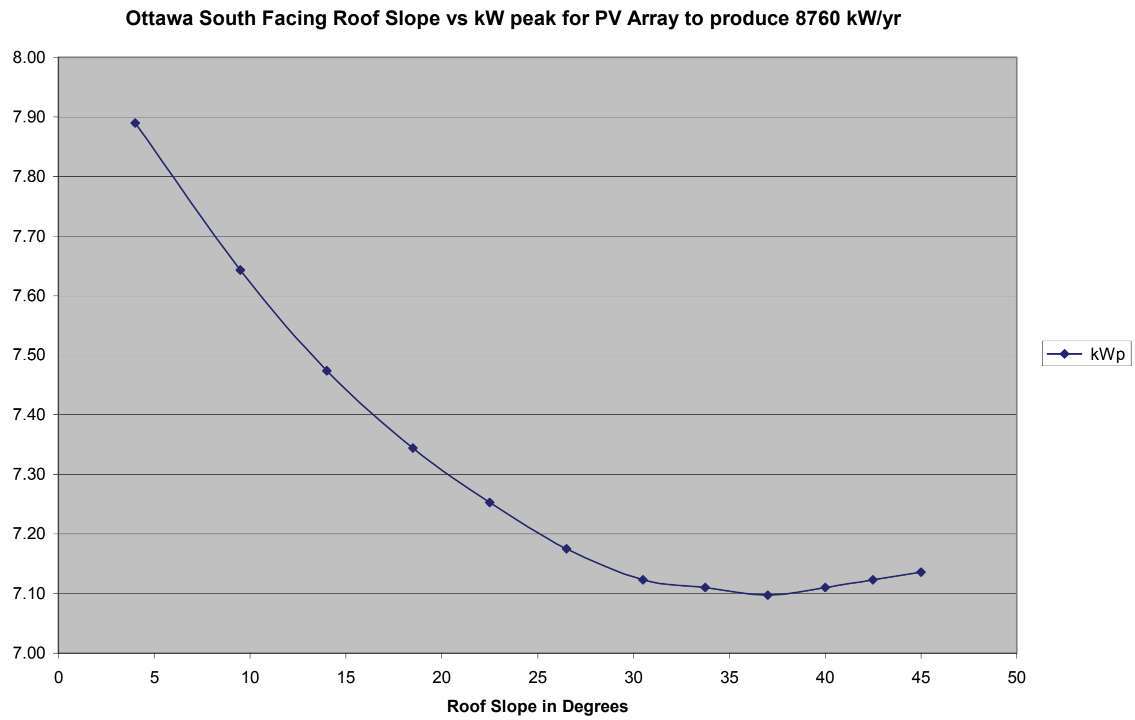
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	61	656.62	7.93
	2 in 12	9.5	61.5	662.00	7.99
	3 in 12	14	61.9	666.31	8.05
	4 in 12	18.5	62.5	672.77	8.12
	5 in 12	22.5	63.2	680.30	8.21
	6 in 12	26.5	63.8	686.76	8.29
	7 in 12	30.5	64.6	695.37	8.40
	8 in 12	33.75	65.3	702.91	8.49
	9 in 12	37	66	710.44	8.58
	10 in 12	40	66.8	719.05	8.68
	11 in 12	42.5	67.5	726.59	8.77
	12 in 12	45	68.2	734.12	8.86
	Vertical Wall	90	90	968.78	11.70

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	59.6	641.55	7.75
	2 in 12	9.5	58.3	627.56	7.58
	3 in 12	14	57.5	618.95	7.47
	4 in 12	18.5	56.8	611.41	7.38
	5 in 12	22.5	56.5	608.18	7.34
	6 in 12	26.5	56.2	604.95	7.31
	7 in 12	30.5	56.1	603.88	7.29
	8 in 12	33.75	56.1	603.88	7.29
	9 in 12	37	56.2	604.95	7.31
	10 in 12	40	56.4	607.10	7.33
	11 in 12	42.5	56.5	608.18	7.34
	12 in 12	45	56.8	611.41	7.38
	Vertical Wall	90	74.4	800.86	9.67

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	59.2	653.39	7.89
	2 in 12	9.5	57.2	632.94	7.64
	3 in 12	14	56.5	618.95	7.47
	4 in 12	18.5	54.9	608.18	7.34
	5 in 12	22.5	54.2	600.65	7.25
	6 in 12	26.5	53.8	594.19	7.18
	7 in 12	30.5	53.4	589.88	7.12
	8 in 12	33.75	53.2	588.81	7.11
	9 in 12	37	53.2	587.73	7.10
	10 in 12	40	53.2	588.81	7.11
	11 in 12	42.5	53.3	589.88	7.12
	12 in 12	45	53.5	590.96	7.14
	Vertical Wall	90	70.8	762.11	9.20


Ottawa East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.00
8.80
8.60
8.40
8.20
8.00
7.80
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Ottawa SE and SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.80
7.70
7.60
7.50
7.40
7.30
7.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp



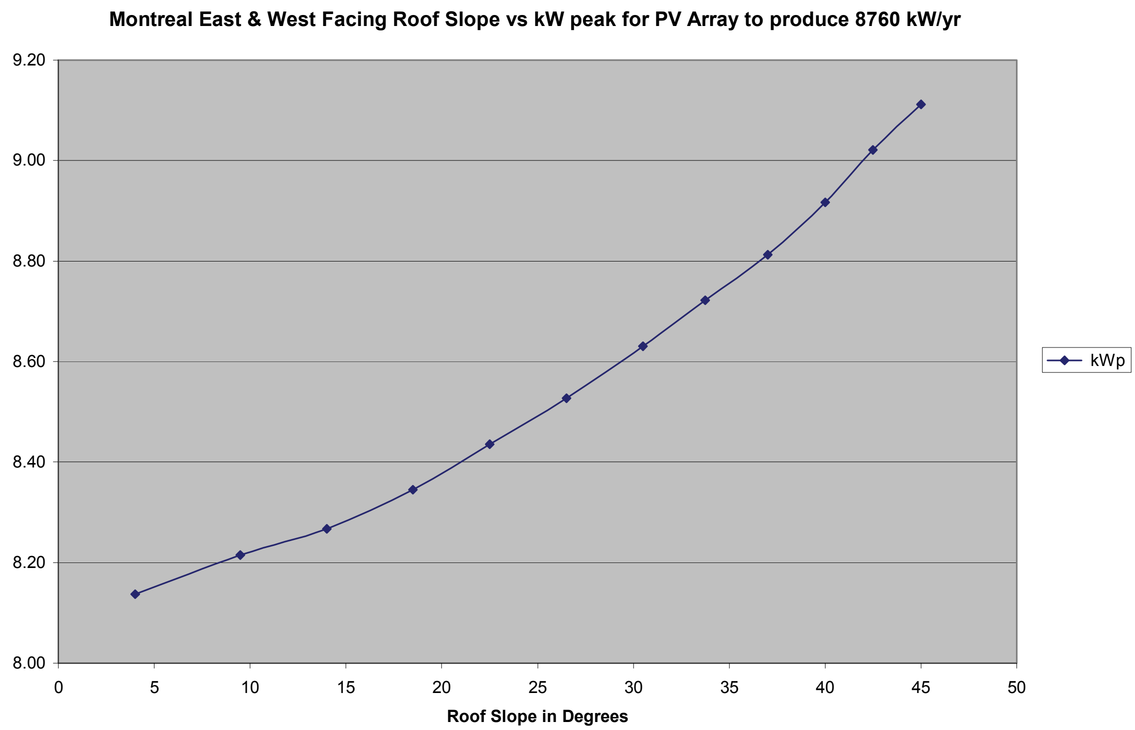
Ottawa South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

Montreal
Annual power production of 8760 kWh/yr | Grid connected system mono-Si 13% efficiency

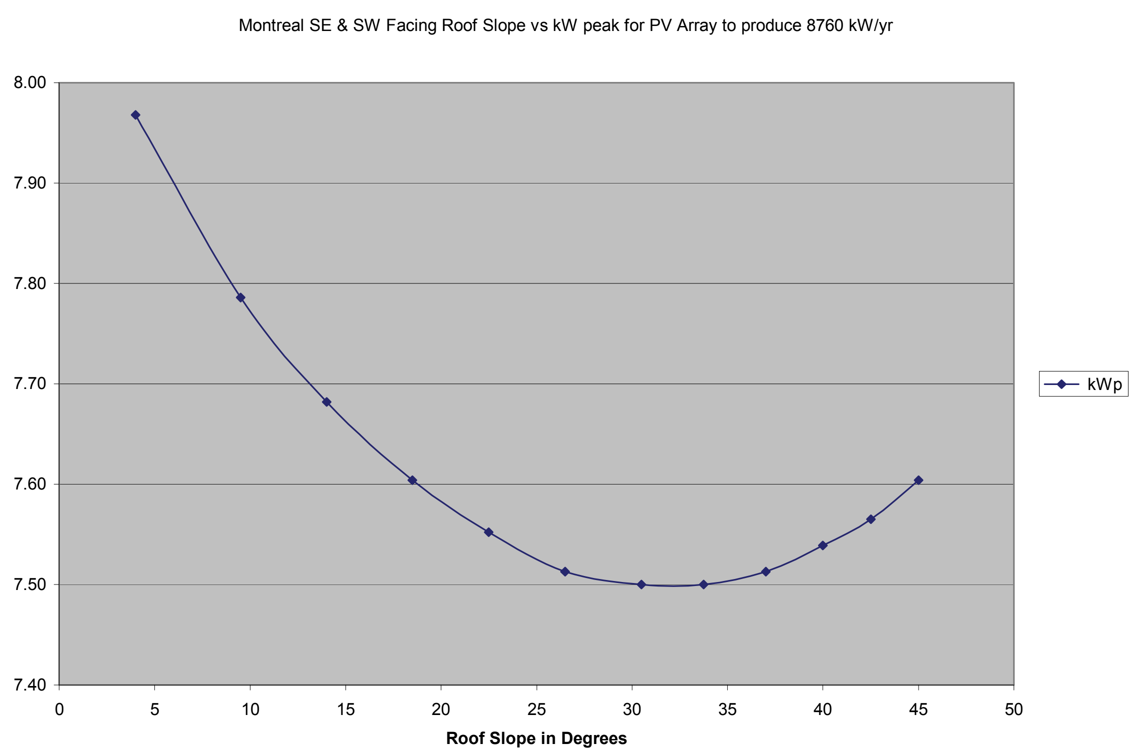
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
East / West	1 in 12	4	62.6	674	8.14
	2 in 12	9.5	63.2	680	8.21
	3 in 12	14	63.6	685	8.27
	4 in 12	18.5	64.2	691	8.34
	5 in 12	22.5	64.9	699	8.44
	6 in 12	26.5	65.6	706	8.53
	7 in 12	30.5	66.4	715	8.63
	8 in 12	33.75	67.1	722	8.72
	9 in 12	37	67.8	730	8.81
	10 in 12	40	68.6	738	8.92
	11 in 12	42.5	69.4	747	9.02
	12 in 12	45	70.1	755	9.11
	Vertical Wall	90	92.8	999	12.06

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
Southeast / Southwest	1 in 12	4	61.3	660	7.97
	2 in 12	9.5	59.9	645	7.79
	3 in 12	14	59.1	636	7.68
	4 in 12	18.5	58.5	630	7.60
	5 in 12	22.5	58.1	625	7.55
	6 in 12	26.5	57.8	622	7.51
	7 in 12	30.5	57.7	621	7.50
	8 in 12	33.75	57.7	621	7.50
	9 in 12	37	57.8	622	7.51
	10 in 12	40	58	624	7.54
	11 in 12	42.5	58.2	626	7.57
	12 in 12	45	58.5	630	7.60
	Vertical Wall	90	76.6	825	9.96

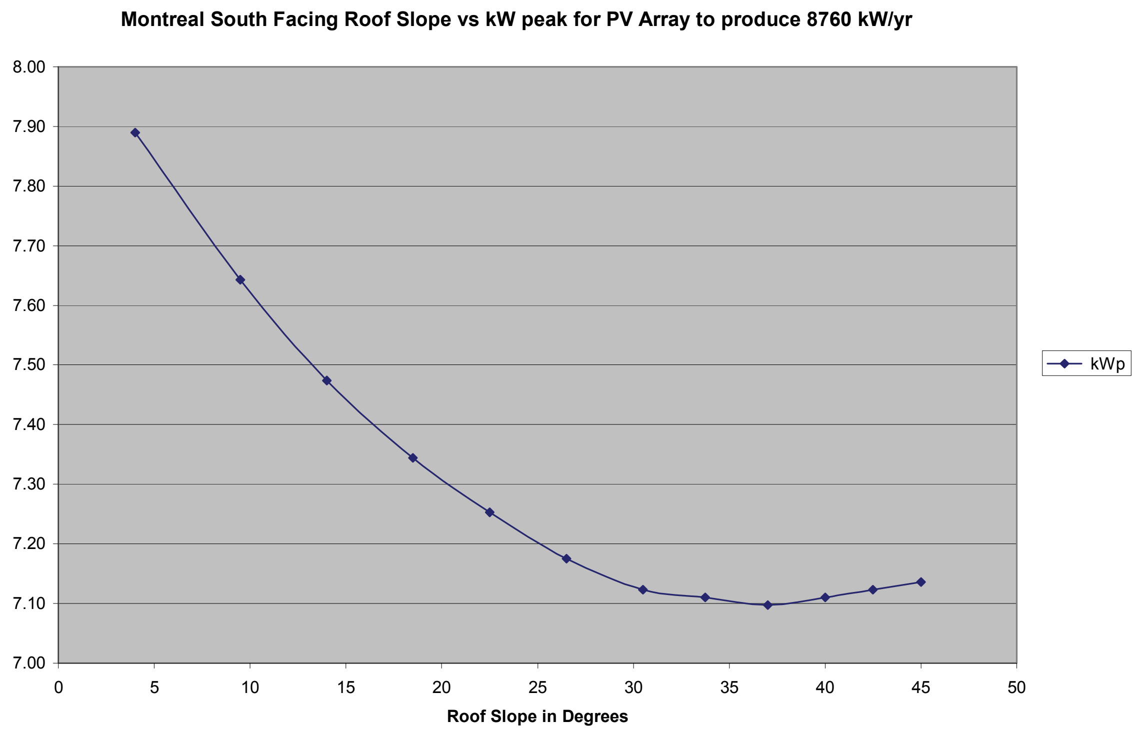
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
South	1 in 12	4	60.7	653	7.89
	2 in 12	9.5	58.8	633	7.64
	3 in 12	14	57.5	619	7.47
	4 in 12	18.5	56.5	608	7.34
	5 in 12	22.5	55.8	601	7.25
	6 in 12	26.5	55.2	594	7.18
	7 in 12	30.5	54.8	590	7.12
	8 in 12	33.75	54.7	589	7.11
	9 in 12	37	54.6	588	7.10
	10 in 12	40	54.7	589	7.11
	11 in 12	42.5	54.8	590	7.12
	12 in 12	45	54.9	591	7.14
	Vertical Wall	90	72.7	783	9.45



Montreal East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.20
9.00
8.80
8.60
8.40
8.20
8.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp



Montreal SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.90
7.80
7.70
7.60
7.50
7.40
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

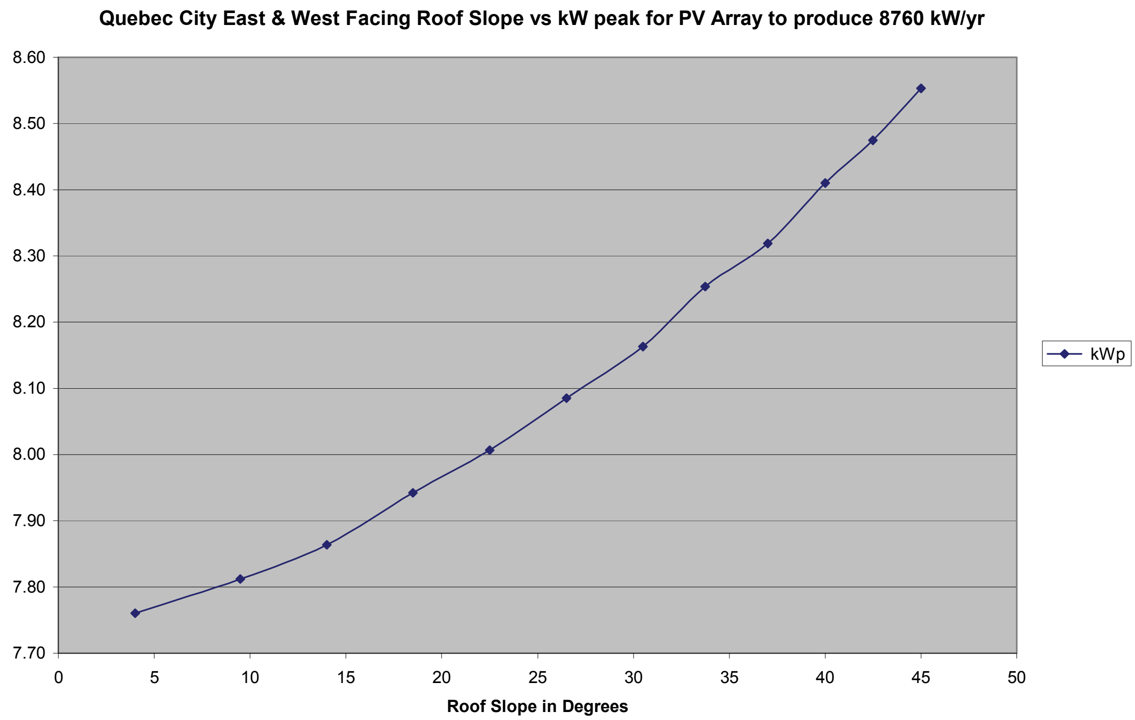

Montreal South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

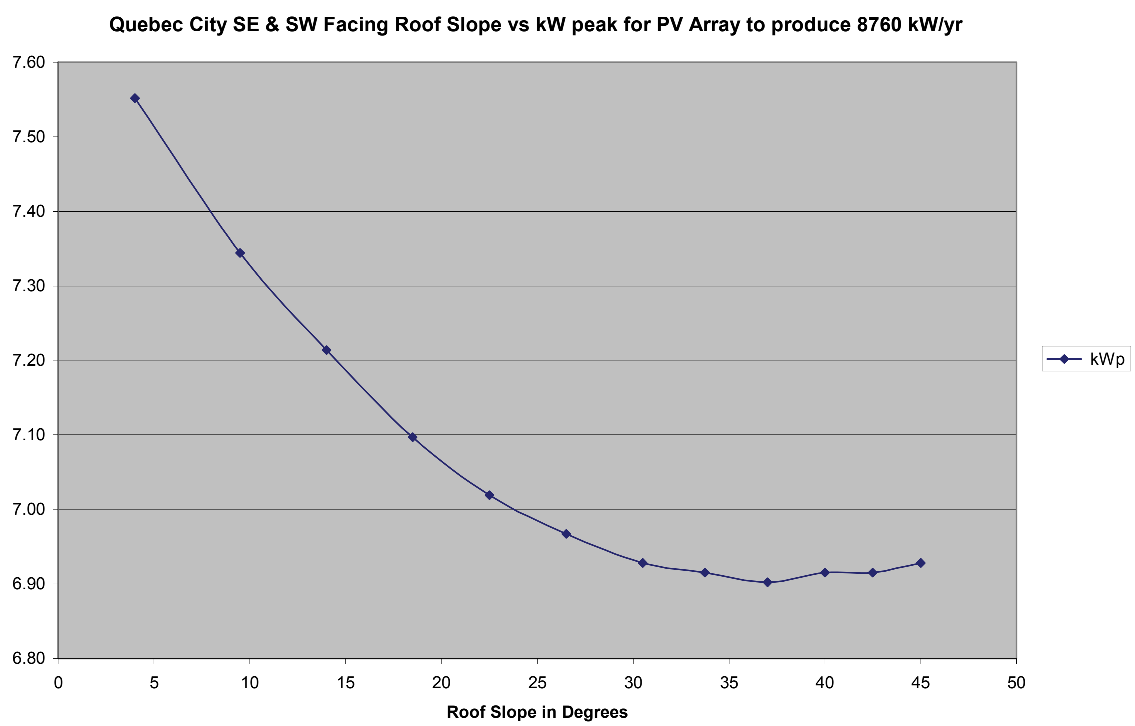
Quebec
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

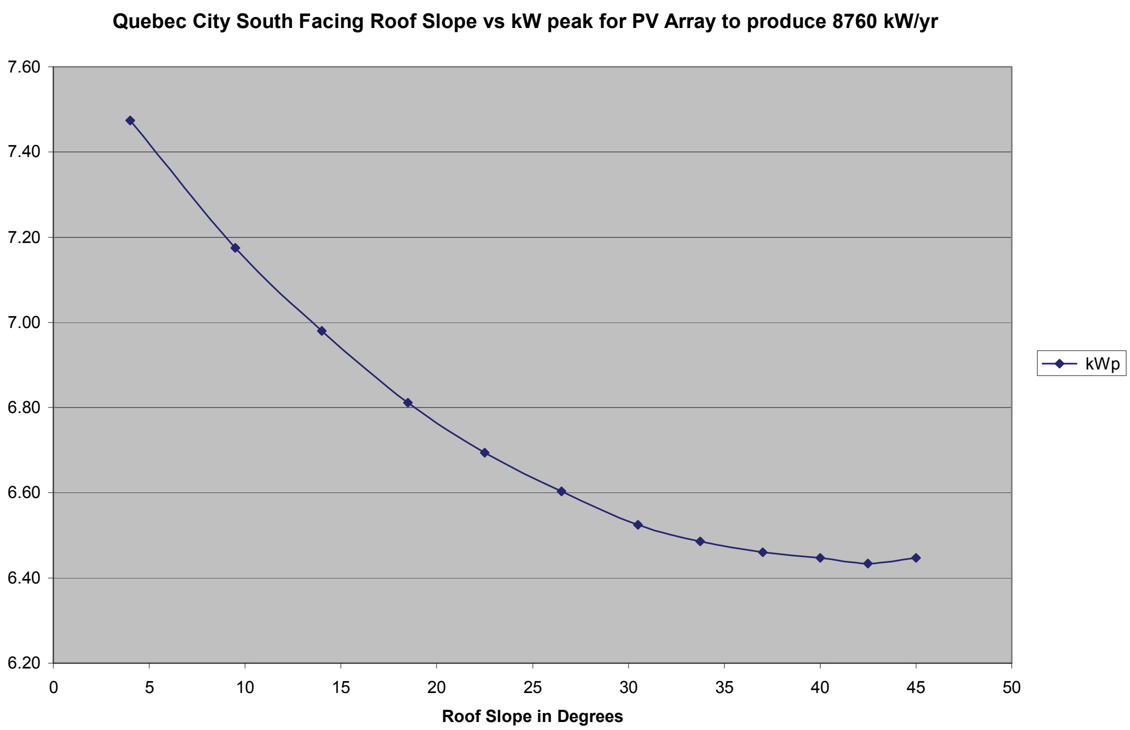
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	59.7	643	7.76
	2 in 12	9.5	60.1	647	7.81
	3 in 12	14	60.5	651	7.86
	4 in 12	18.5	61.1	658	7.94
	5 in 12	22.5	61.6	663	8.01
	6 in 12	26.5	62.2	670	8.08
	7 in 12	30.5	62.8	676	8.16
	8 in 12	33.75	63.5	684	8.25
	9 in 12	37	64	689	8.32
	10 in 12	40	64.7	696	8.41
	11 in 12	42.5	65.2	702	8.47
	12 in 12	45	65.8	708	8.55
	Vertical wall	90	84.5	910	10.98

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Soutwest	1 in 12	4	58.1	625	7.55
	2 in 12	9.5	56.5	608	7.34
	3 in 12	14	55.5	597	7.21
	4 in 12	18.5	54.6	588	7.10
	5 in 12	22.5	54	581	7.02
	6 in 12	26.5	53.6	577	6.97
	7 in 12	30.5	53.3	574	6.93
	8 in 12	33.75	53.2	573	6.92
	9 in 12	37	53.1	572	6.90
	10 in 12	40	53.2	573	6.92
	11 in 12	42.5	53.2	573	6.92
	12 in 12	45	53.3	574	6.93
	Vertical wall	90	65.8	708	8.55

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	57.5	619	7.47
	2 in 12	9.5	55.2	594	7.18
	3 in 12	14	53.7	578	6.98
	4 in 12	18.5	52.4	564	6.81
	5 in 12	22.5	51.5	554	6.69
	6 in 12	26.5	50.8	547	6.60
	7 in 12	30.5	50.2	540	6.53
	8 in 12	33.75	49.9	537	6.49
	9 in 12	37	49.7	535	6.46
	10 in 12	40	49.6	534	6.45
	11 in 12	42.5	49.5	533	6.43
	12 in 12	45	49.6	534	6.45
	Vertical wall	90	62.7	675	8.15


Quebec City East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.60
8.50
8.40
8.30
8.20
8.10
8.00
7.90
7.80
7.70
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Quebec City SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
6.80
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

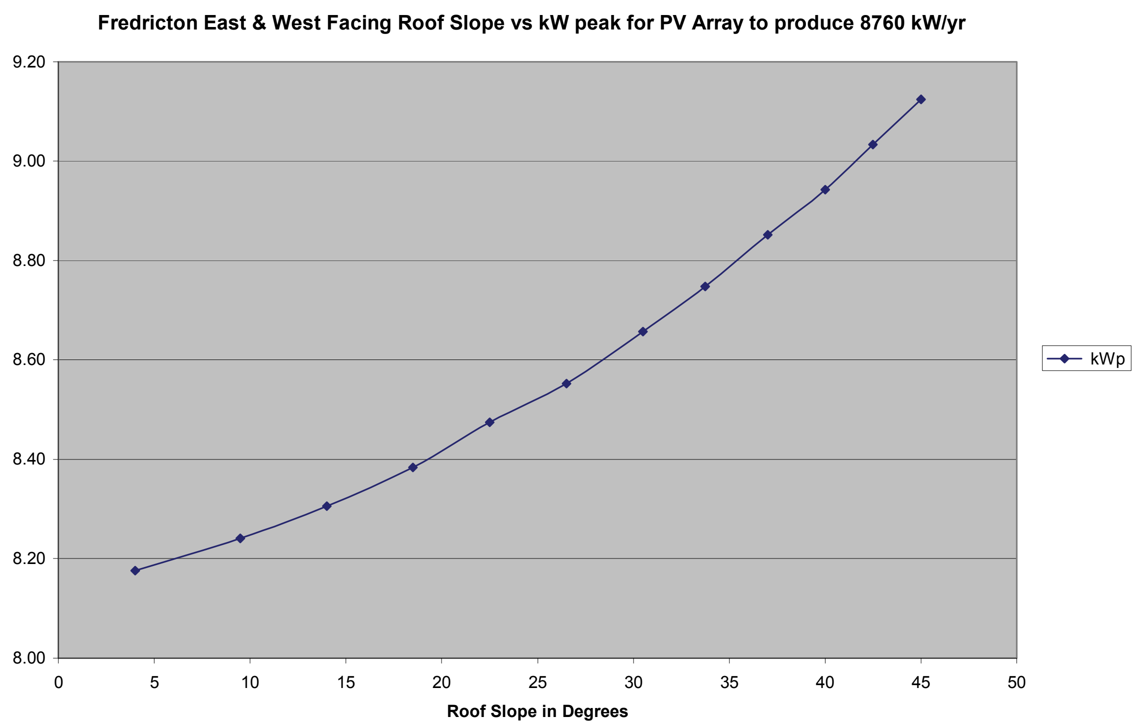

Quebec City South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.60
7.40
7.20
7.00
6.80
6.60
6.40
6.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

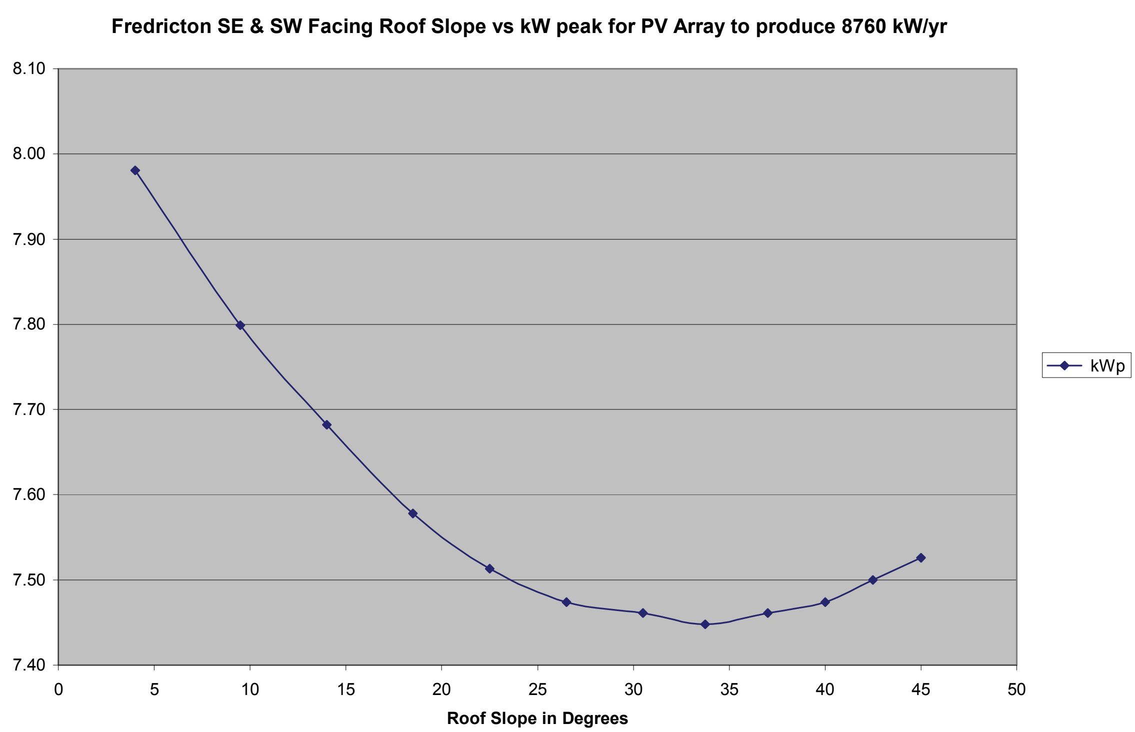
Fredricton
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

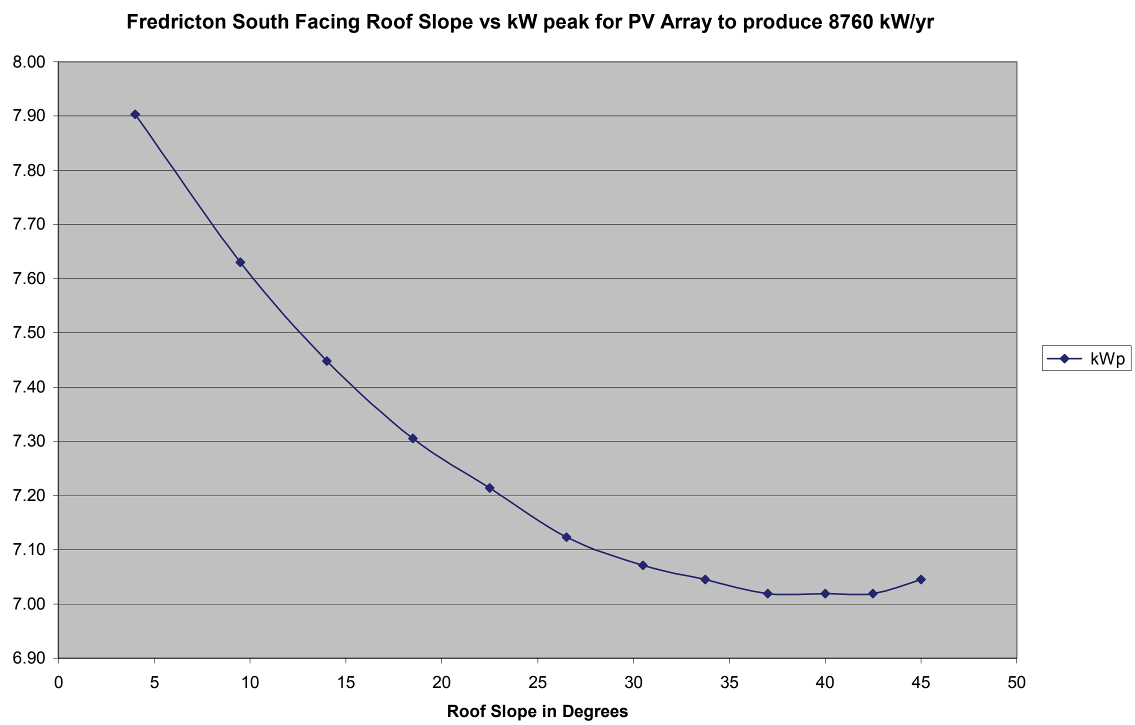
	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
East / West	1 in 12	4	62.9	677	8.18
	2 in 12	9.5	63.4	682	8.24
	3 in 12	14	63.9	688	8.31
	4 in 12	18.5	64.5	694	8.38
	5 in 12	22.5	65.2	702	8.47
	6 in 12	26.5	65.8	708	8.55
	7 in 12	30.5	66.6	717	8.66
	8 in 12	33.75	67.3	724	8.75
	9 in 12	37	68.1	733	8.85
	10 in 12	40	68.8	741	8.94
	11 in 12	42.5	69.5	748	9.03
	12 in 12	45	70.2	756	9.12
	Vertical wall	90	92.7	998	12.05

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
Southeast / Southwest	1 in 12	4	61.4	661	7.98
	2 in 12	9.5	60	646	7.80
	3 in 12	14	59.1	636	7.68
	4 in 12	18.5	58.3	628	7.58
	5 in 12	22.5	57.8	622	7.51
	6 in 12	26.5	57.5	619	7.47
	7 in 12	30.5	57.4	618	7.46
	8 in 12	33.75	57.3	617	7.45
	9 in 12	37	57.4	618	7.46
	10 in 12	40	57.5	619	7.47
	11 in 12	42.5	57.7	621	7.50
	12 in 12	45	57.9	623	7.53
	Vertical wall	90	75.2	809	9.77

	Slope Rise and Run	Slope	Estimated Collector Area Required		Nominal PV Array Power
Direction	Inches	Degrees	m^2	ft^2	kWp
South	1 in 12	4	60.8	654	7.90
	2 in 12	9.5	58.7	632	7.63
	3 in 12	14	57.3	617	7.45
	4 in 12	18.5	56.2	605	7.31
	5 in 12	22.5	55.5	597	7.21
	6 in 12	26.5	54.8	590	7.12
	7 in 12	30.5	54.4	586	7.07
	8 in 12	33.75	54.2	583	7.05
	9 in 12	37	54	581	7.02
	10 in 12	40	54	581	7.02
	11 in 12	42.5	54	581	7.02
	12 in 12	45	54.2	583	7.05
	Vertical wall	90	70.7	761	9.19


Fredricton East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.20
9.00
8.80
8.60
8.40
8.20
8.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Fredricton SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.10
8.00
7.90
7.80
7.70
7.60
7.50
7.40
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp



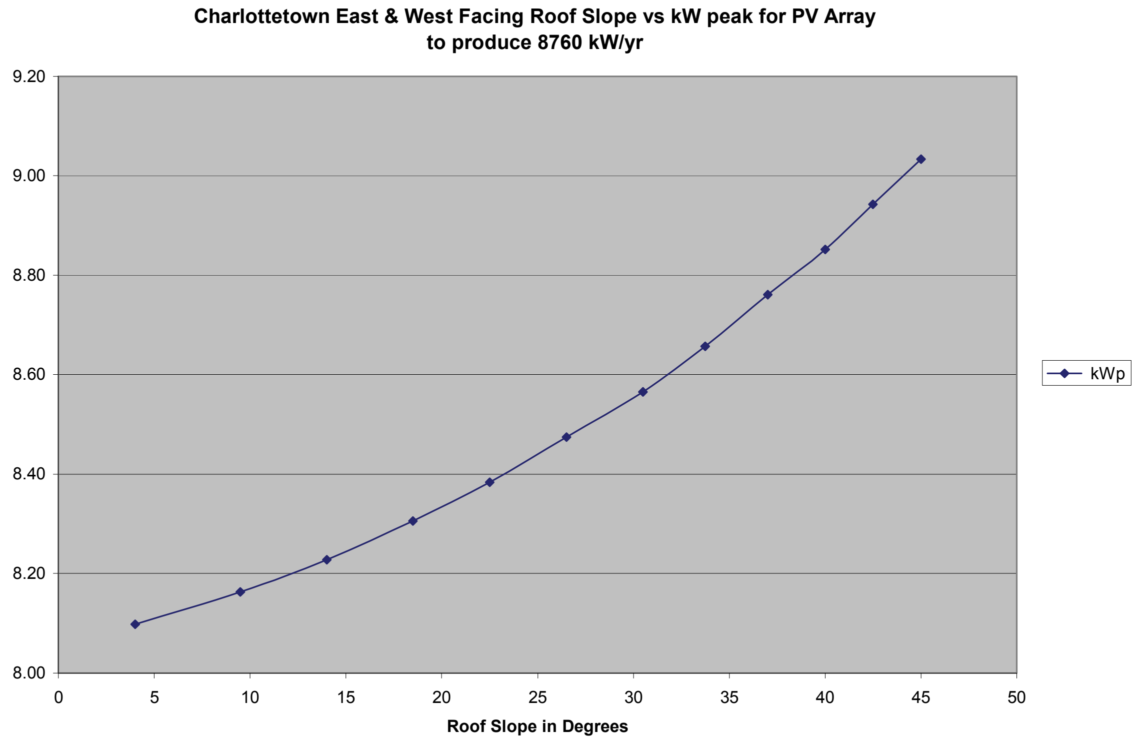
Fredricton South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

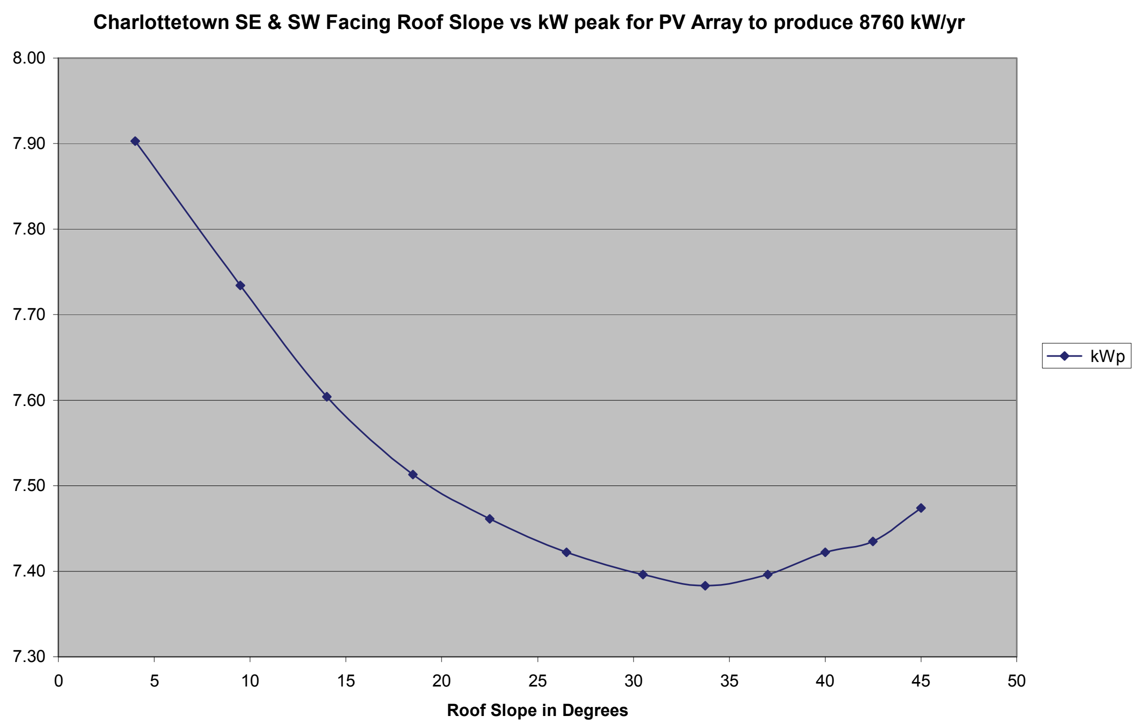
Charlottetown
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

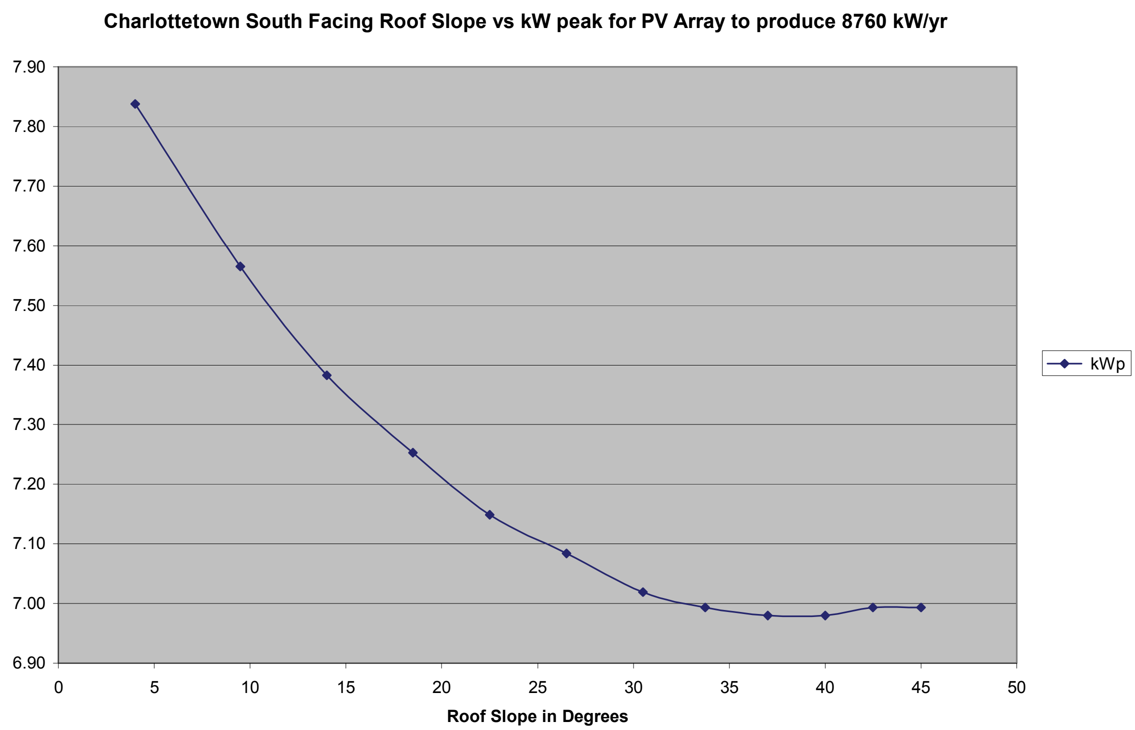
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	62.3	671	8.10
	2 in 12	9.5	62.8	676	8.16
	3 in 12	14	63.3	681	8.23
	4 in 12	18.5	63.9	688	8.31
	5 in 12	22.5	64.5	694	8.38
	6 in 12	26.5	65.2	702	8.47
	7 in 12	30.5	65.9	709	8.57
	8 in 12	33.75	66.6	717	8.66
	9 in 12	37	67.4	726	8.76
	10 in 12	40	68.1	733	8.85
	11 in 12	42.5	68.8	741	8.94
	12 in 12	45	69.5	748	9.03
	Vertical wall	90	80.8	870	10.50

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	60.8	654	7.90
	2 in 12	9.5	59.5	640	7.73
	3 in 12	14	58.5	630	7.60
	4 in 12	18.5	57.8	622	7.51
	5 in 12	22.5	57.4	618	7.46
	6 in 12	26.5	57.1	615	7.42
	7 in 12	30.5	56.9	612	7.40
	8 in 12	33.75	56.8	611	7.38
	9 in 12	37	56.9	612	7.40
	10 in 12	40	57.1	615	7.42
	11 in 12	42.5	57.2	616	7.44
	12 in 12	45	57.5	619	7.47
	Vertical wall	90	74.5	802	9.68

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	60.3	649	7.84
	2 in 12	9.5	58.2	626	7.57
	3 in 12	14	56.8	611	7.38
	4 in 12	18.5	55.8	601	7.25
	5 in 12	22.5	55	592	7.15
	6 in 12	26.5	54.5	587	7.08
	7 in 12	30.5	54	581	7.02
	8 in 12	33.75	53.8	579	6.99
	9 in 12	37	53.7	578	6.98
	10 in 12	40	53.7	578	6.98
	11 in 12	42.5	53.8	579	6.99
	12 in 12	45	53.8	579	6.99
	Vertical wall	90	70.4	758	9.15


Charlottetown East & West Facing Roof Slope vs kW peak for PV Array
to produce 8760 kW/yr
9.20
9.00
8.80
8.60
8.40
8.20
8.00
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Charlottetown SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


Charlottetown South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
7.00
6.90
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

Halifax

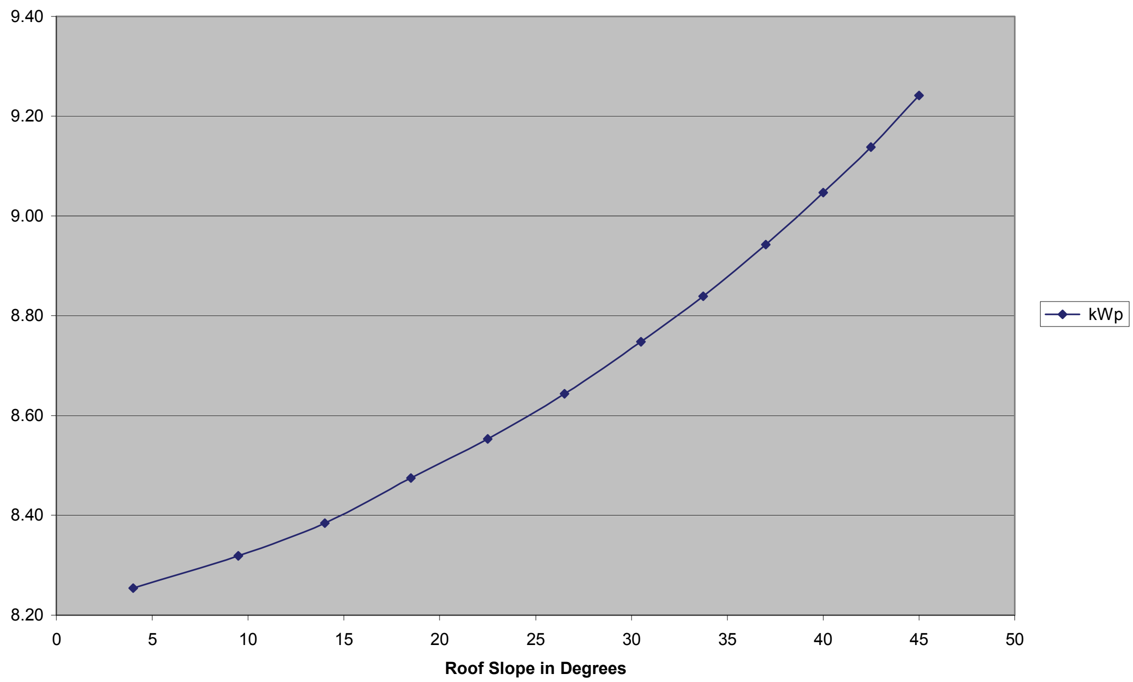
Annual power production of 8760 kWh/yr Grid connected system mono-Si 13% efficiency

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	63.5	684	8.25
	2 in 12	9.5	64	689	8.32
	3 in 12	14	64.5	694	8.38
	4 in 12	18.5	65.2	702	8.47
	5 in 12	22.5	65.8	708	8.55
	6 in 12	26.5	66.5	716	8.64
	7 in 12	30.5	67.3	724	8.75
	8 in 12	33.75	68	732	8.84
	9 in 12	37	68.8	741	8.94
	10 in 12	40	69.6	749	9.05
	11 in 12	42.5	70.3	757	9.14
	12 in 12	45	71.1	765	9.24
	Vertical wall	90	94.8	1020	12.32

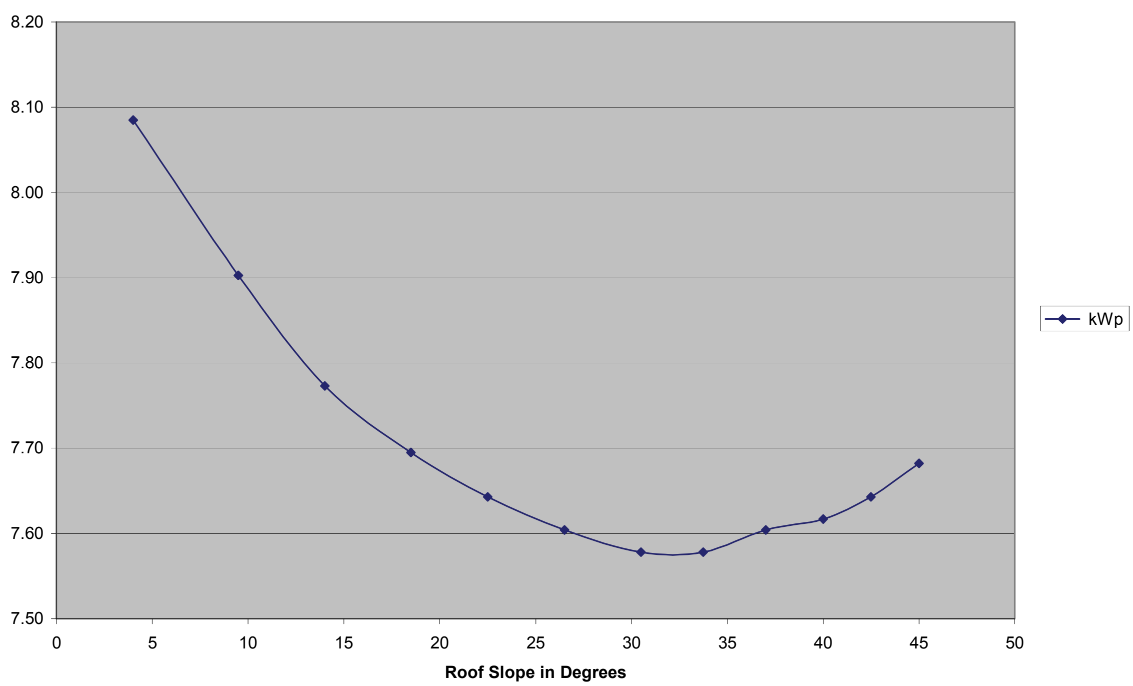
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast /Southwest	1 in 12	4	62.2	670	8.08
	2 in 12	9.5	60.8	654	7.90
	3 in 12	14	59.8	644	7.77
	4 in 12	18.5	59.2	637	7.69
	5 in 12	22.5	58.8	633	7.64
	6 in 12	26.5	58.5	630	7.60
	7 in 12	30.5	58.3	628	7.58
	8 in 12	33.75	58.3	628	7.58
	9 in 12	37	58.5	630	7.60
	10 in 12	40	58.6	631	7.62
	11 in 12	42.5	58.8	633	7.64
	12 in 12	45	59.1	636	7.68
	Vertical wall	90	77.5	834	10.07

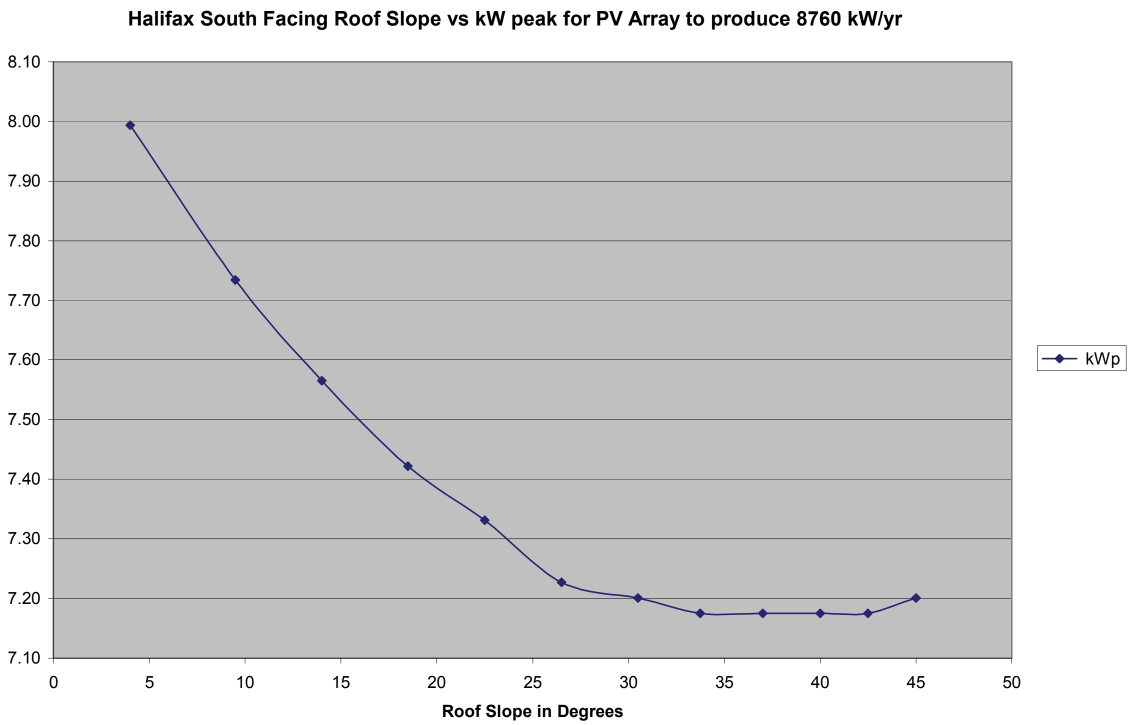
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	61.5	662	7.99
	2 in 12	9.5	59.5	640	7.73
	3 in 12	14	58.2	626	7.57
	4 in 12	18.5	57.1	615	7.42
	5 in 12	22.5	56.4	607	7.33
	6 in 12	26.5	55.6	598	7.23
	7 in 12	30.5	55.4	596	7.20
	8 in 12	33.75	55.2	594	7.18
	9 in 12	37	55.2	594	7.18
	10 in 12	40	55.2	594	7.18
	11 in 12	42.5	55.2	594	7.18
	12 in 12	45	55.4	596	7.20
	Vertical wall	90	73	786	9.49

Halifax East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr



Halifax SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr




Halifax South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
8.10
8.00
7.90
7.80
7.70
7.60
7.50
7.40
7.30
7.20
7.10
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

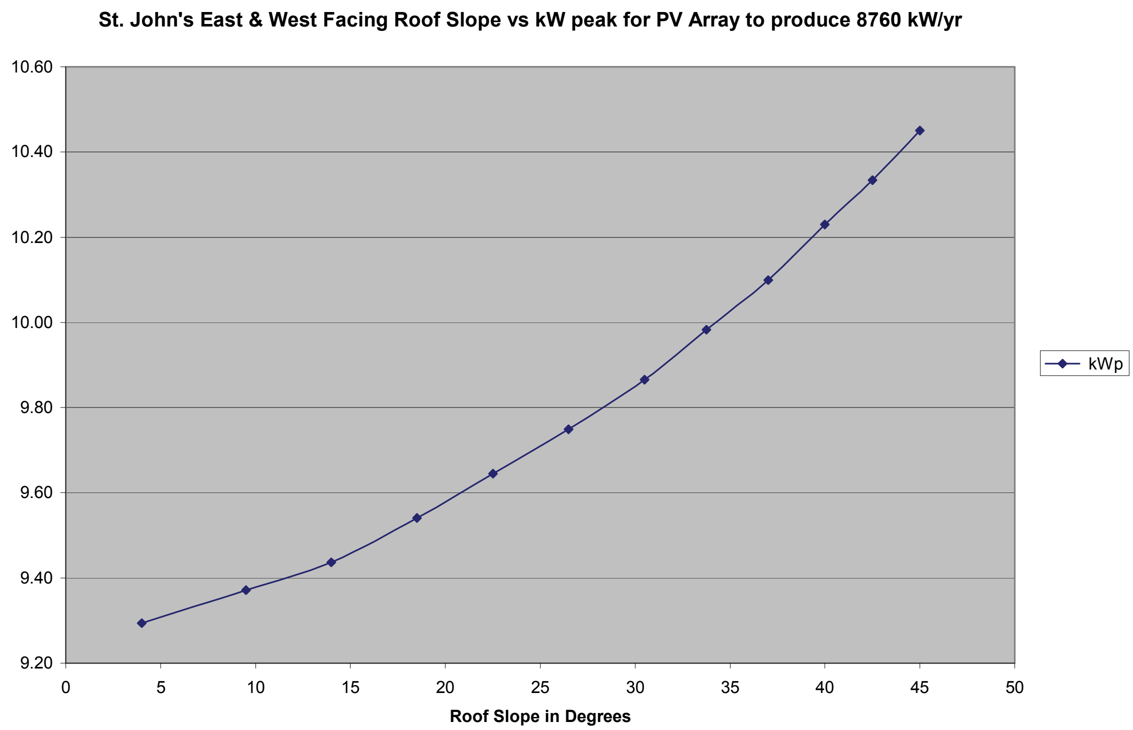
St. John's

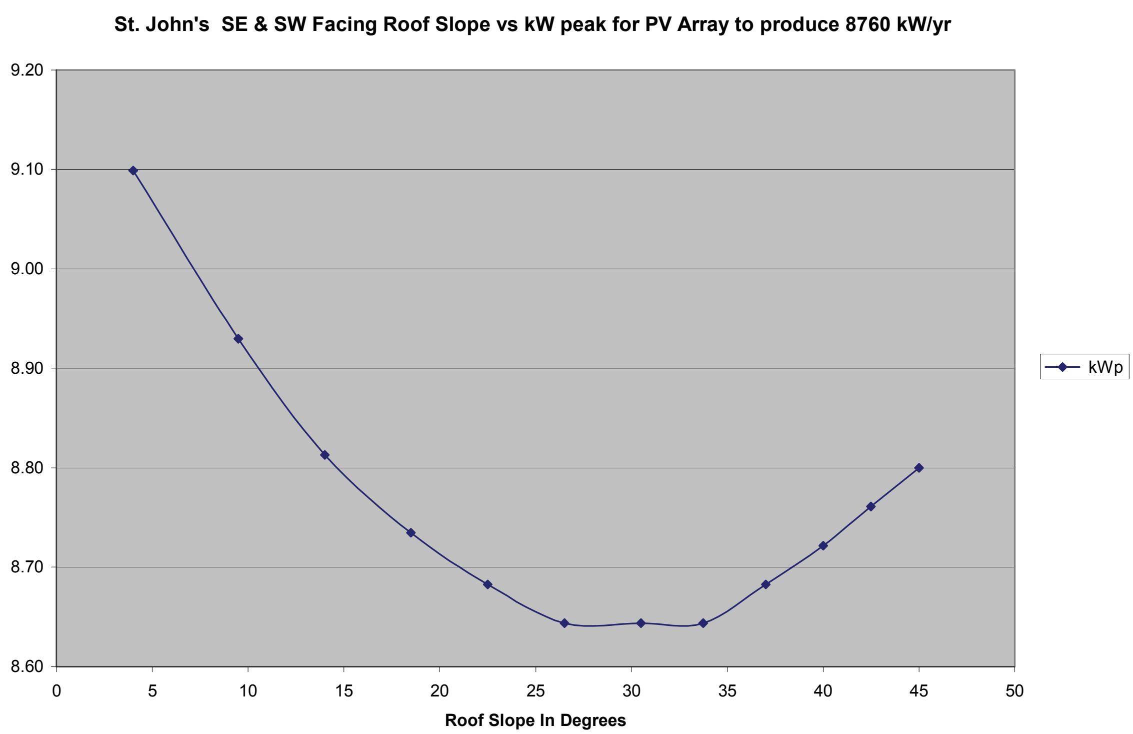
Annual power production of 8760 kWh/yr — Grid connected system mono-Si 13% efficiency

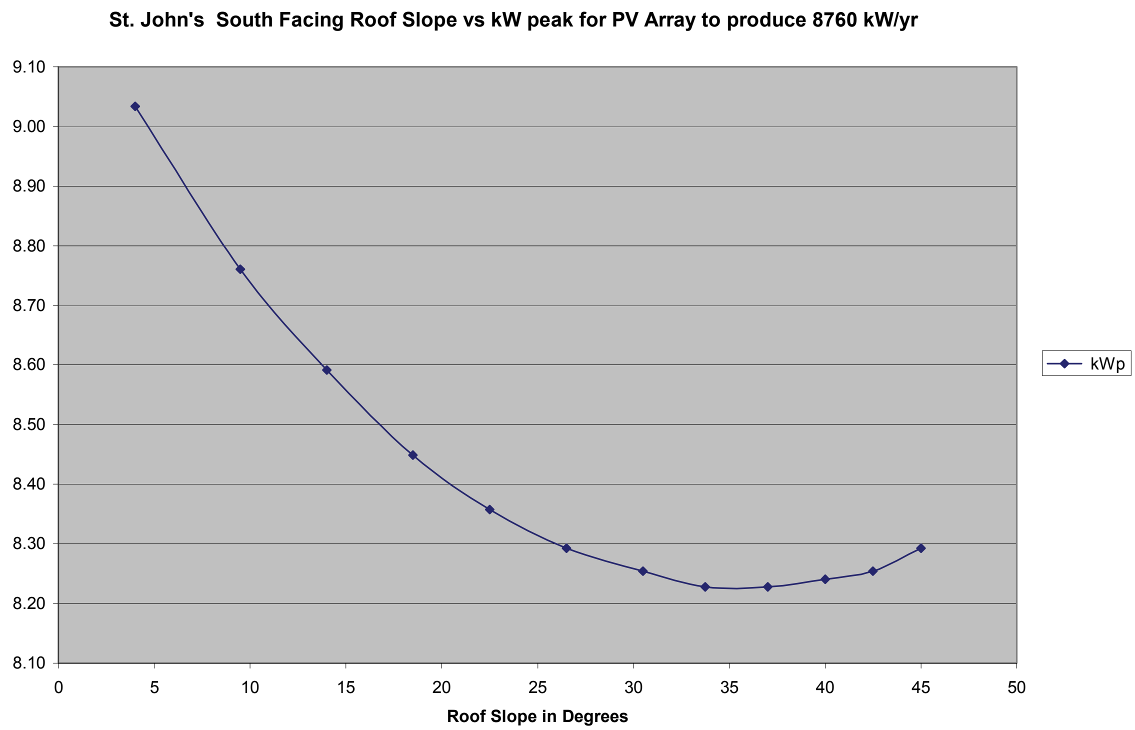
Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
East / West	1 in 12	4	71.5	770	9.29
	2 in 12	9.5	72.1	776	9.37
	3 in 12	14	72.6	781	9.44
	4 in 12	18.5	73.4	790	9.54
	5 in 12	22.5	74.2	799	9.64
	6 in 12	26.5	75	807	9.75
	7 in 12	30.5	75.9	817	9.87
	8 in 12	33.75	76.8	827	9.98
	9 in 12	37	77.7	836	10.10
	10 in 12	40	78.7	847	10.23
	11 in 12	42.5	79.5	856	10.33
	12 in 12	45	80.4	865	10.45
	Vertical wall	90	108.3	1166	14.08

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
Southeast / Southwest	1 in 12	4	70	753	9.10
	2 in 12	9.5	68.7	740	8.93
	3 in 12	14	67.8	730	8.81
	4 in 12	18.5	67.2	723	8.73
	5 in 12	22.5	66.8	719	8.68
	6 in 12	26.5	66.5	716	8.64
	7 in 12	30.5	66.5	716	8.64
	8 in 12	33.75	66.5	716	8.64
	9 in 12	37	66.8	719	8.68
	10 in 12	40	67.1	722	8.72
	11 in 12	42.5	67.4	726	8.76
	12 in 12	45	67.7	729	8.80
	Vertical wall	90	89.8	967	11.67

Direction	Slope Rise and Run Inches	Slope Degrees	Estimated Collector Area Required m^2	ft^2	Nominal PV Array Power kWp
South	1 in 12	4	69.5	748	9.03
	2 in 12	9.5	67.4	726	8.76
	3 in 12	14	66.1	712	8.59
	4 in 12	18.5	65	700	8.45
	5 in 12	22.5	64.3	692	8.36
	6 in 12	26.5	63.8	687	8.29
	7 in 12	30.5	63.5	684	8.25
	8 in 12	33.75	63.3	681	8.23
	9 in 12	37	63.3	681	8.23
	10 in 12	40	63.4	682	8.24
	11 in 12	42.5	63.5	684	8.25
	12 in 12	45	63.8	687	8.29
	Vertical wall	90	85	915	11.05


St. John's East & West Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
10.60
10.40
10.20
10.00
9.80
9.60
9.40
9.20
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp


St. John's SE & SW Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.20
9.10
9.00
8.90
8.80
8.70
8.60
0
5
10
15
20
25
30
35
40
45
50
Roof Slope In Degrees
kWp


St. John's South Facing Roof Slope vs kW peak for PV Array to produce 8760 kW/yr
9.10
9.00
8.90
8.80
8.70
8.60
8.50
8.40
8.30
8.20
8.10
0
5
10
15
20
25
30
35
40
45
50
Roof Slope in Degrees
kWp

Appendix G: EGH* Rating Detailed Calculations

The EGH* rating is defined as

$$\text{EGH* rating} = 100 - \left(\left(\frac{\text{Annual Estimated Energy Consumption}}{\text{Reference Energy Consumption}}\right) * 20\right)$$

It is calculated in two steps

1. Determine the Reference Energy Consumption from the following equation:
Reference Energy Consumption = Space Heating Benchmark + DHW Benchmark + Baseload Benchmark + Air Conditioning Energy

$$\text{Space Heating Benchmark} = S^* \left(\frac{49 * \text{Degree Days}}{6000}\right) * \left(40 + \frac{V}{2.5}\right)$$

Where S = 4.5 megajoules (MJ) for fuel fired space heating systems or
S= 3.6 megajoules (MJ) for electric space heating systems

DD = Celsius heating degree-days for the locality (18°C base) (Available from the HOT2000 weather file)
V= Interior heated volume, including the basement, in cubic meters.

DHW Benchmark = 47445 * W * (55-Tw)/(55-9.5)
Where:
Tw = local water mains temperature. From the HOT2000 weather file (average deep ground temperature)
W = 6.19 megjoules for fuel fired DHW systems or
W = 3.87 megajoules (MJ) for electric DHW systems

Baseload benchmark = 31,536 MJ

Air Conditioning Energy = Space Cooling Electricity in MJ from HOT2000 run.

2. Determine Annual Estimated Energy Consumption

- For all designs the Annual Estimated Energy Consumption is equal to the Total House Energy Use in the HOT2000 run, with deductions for DHW and base load reductions.
- Subtract Solar DHW from Total House Energy Use (in the EQuilibrium Housing Initiative, this was calculated within HOT2000, in this study, the Solar DHW contribution was more precisely calculated in RETScreen, and those values were subtracted from the Total House Energy Use)
- Subtract the PV system contribution (as modelled in RETScreen) from the Total House Energy Use.