RETROFITTING SUBURBAN HOMES FOR RESILIENCY

RETROFITTING SUBURBAN HOMES FOR RESILIENCY:

A PROTOTYPE DECISION SUPPORT SYSTEM

BY

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ABSTRACT

North American suburbs are facing widespread decline and obsolescence. They cannot meet the needs of North America's ageing society, nor are they equipped to handle climate change or higher energy prices. Compounded with their negative environmental impact, the suburbs can be accurately labeled as non-resilient.

More resilient suburban communities can be realized through retrofitting the suburbs. Retrofitting can help suburbs adapt to meet current and future needs. Retrofitting at the community scale is in the early stages of development. However, at the house-level, retrofitting tools exist but must be synthesized into a useable form for homeowners.

Homeowners arguably have the largest stake in the future of the suburbs. People are attached to their homes for both financial and social reasons. Empowering them with tools to make their suburban home and community more resilient is considered to be highly desirable.

This thesis empowers homeowners by developing a prototype decision support system (DSS) that they (or their contractors) will use to make choices to help them adapt and retrofit their home for resilience. This Microsoft Excel-based DSS addresses the need for new types of housing, the need to reduce the environmental impact of the home, and the need for the home to decrease reliance on fossil fuels. The DSS does this through its three constituent 'modules'.

The first module, Dividing Suburban Homes, demonstrates the feasibility of dividing large suburban homes into multifamily dwellings. The second module, Sustainable Additions, helps homeowners select resilient building materials for housing additions. The last module, Reducing the Home's Environmental Impact, helps homeowners choose methods for reducing both the environmental impact of their home as well as reducing the home's fossil fuel usage.

Through these three modules, this DSS addresses a considerable number of the current and anticipated needs for retrofitting the suburbs.

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1. INTRODUCTION

1.1. THE NEED FOR SUBURBAN CHANGE

North America is facing large-scale economic and environmental changes and adaptation is needed if our quality of life is to be upheld. There is uncertainty in future energy prices and availability due to geopolitical and geologic factors. Climate change also poses threats that will require adaptation of our collective infrastructure. Increased urbanization and exploitation of natural resources has created considerable stresses on ecosystems such that many are in decline or severely degraded. This has created environmental movements to reduce the impact of our society on these ecosystems. Shifting demographics, such as the surge in the population of seniors as baby boomers move into their 60's and 70's is increasing demands on certain services and products while lessening demands on others.

Much of this change will affect the suburbs, the place where approximately half of the North American population currently lives. There is stress on aging infrastructure as municipalities struggle to pay for the costly replacement of suburban infrastructure (Blais, 2011; ASCE, 2009). The demand for different types of housing is increasing, as baby boomers need more accessible homes of a different type and size. Suburbs require large amounts of fossil fuels to operate and increases in energy prices affect their viability. Decline, in part due to these factors has already plagued many suburbs and has become so prevalent that there are few large North American cities exempt from suburb decline and degradation (Nelson, 2006).

This impact has created a need to rethink the suburbs. There are mature models for the greenfield or brownfield development of sustainable and resilient new housing. However the same maturity does not exist in terms of adaptation of existing suburbs to increase their resiliency and relevance under changing circumstances. The suburbs are so ubiquitous that demolishing and starting over is simply too costly an option, both financially and ecologically.

1.2. EMPOWERING HOMEOWNERS

Homeowners arguably have the largest stake in the future of the suburbs. People are attached to their homes for both financial and social reasons. Empowering them to make their suburban community more resilient and able to prosper in times of stressful change is needed. They need to be given the tools to make good choices about how they will adapt their homes in the future and informed about what opportunities are available.

This thesis addresses this need by developing a prototype decision support system (DSS) that homeowners (or their contractors) will use to make choices to help them adapt and retrofit their home for resilience. The Microsoft Excel-based DSS addresses the need for new types of housing, the need to reduce the environmental impact of the home, and the need for the home to decrease reliance on fossil fuels. The DSS does this through its three constituent parts or 'modules'.

The first module, Dividing Suburban Homes, shows homeowners the feasibility of dividing large suburban homes into multifamily dwellings. There are many situations were a divided home could serve a beneficial purpose. Empty nesters may find an extra source of income in the extra space left when children leave. An elderly parent may want to move to be closer to help care for children, to benefit from less yard work, or to have a watchful eye if their health is in question. A smaller home also becomes a more affordable home should there be changes to income. These are just a few of the benefits that could be realized from dividing a home.

The second module, Sustainable Additions, helps homeowners select resilient building materials for housing additions. There are many building materials that could be used for home construction but from this large selection only a few are widely used, and they are not very resilient. Using building materials that are suited to the local climate, can be sourced locally, and can help reduce the home's energy use are recommended in this module since they are more resilient.

The last module, Reducing the Home's Environmental Impact, helps homeowners choose which tactics are best for reducing both the environmental impact their home as well as reducing the home's need for fossil fuels. The Environmental Impact module also contains design tools that can be used for preliminary design of some of the tactics suggested. Through these three modules, this DSS addresses a considerable number of the current and anticipated needs for retrofitting the suburbs.

1.3. THESIS STRUCTURE

The DSS was created through research into existing technologies and approaches and the synthesis of this research into a useable form. Chapter 2 provides a literature review relevant to suburban retrofitting and green building. It investigates what the suburbs are and current efforts to retrofit the suburbs. This review shows the trends in demographics, geopolitical issues and geological realities that make retrofitting the suburbs relevant today. The barriers to successful retrofitting are examined. Finally green building certification systems are explored to understand how the industry views and rates green buildings.

Chapter 3 takes the information from Chapter 2and conceptualizes what a DSS would look like that could address the issues presented. This chapter develops the three modules in conceptual form and analyzes the function and required outcome of each module. Further literature review is completed for each module to develop technical content as necessary.

Chapter 4 documents the detailed development of the DSS. This chapter shows how each module was taken from concepts to a useable tool. Each aspect is more fully explored and any further research into specific topics is noted. The three modules are linked together in a way that they can be used either individually or as an integrated whole.

Chapter 5 applies the DSS to three example homes. The homes represent various types of suburban homes from different eras ranging from post-war to present day. Relevant conclusions are drawn regarding the ability of the DSS to address the needs previously identified and the suitability of various homes for retrofitting.

Chapter 6 develops some conclusions from the thesis, making note of important findings and conclusions derived from background research, the development of the DSS and the application of the DSS. Areas for further work are recommended ranging from further refinement of the DSS to larger issues pertaining to suburban retrofitting and suburban resilience.

Moving to Chapter 2, this thesis can begin to explore the complexity of the suburbs and suburban retrofitting.

2. LITERATURE REVIEW: SUBURBAN RETROFITTING AND GREEN BUILDING METHODS

2.1. SUBURBAN RETROFITTING

Given the ubiquitous nature of urban sprawl in North America, there have been many critiques analyzing the problems with this type of development. Many authors have adequately characterized what is wrong with sprawl and created models of how to plan new development that can avoid the pitfalls of urban sprawl (Churchill & Baetz, 1999). An emerging field of study in urban planning has identified that in addition to changing the paradigm of greenfield-based urban sprawl, we must look to existing sprawl developments and find way to retrofit these suburbs (Tachieva, 2010, Dunham-Jones & Williamson, 2009, Randall, 2001; Nelson, 2006). The following sections outline the difference between sprawl and suburban development; present the current state of suburban retrofitting, including the philosophy behind suburban retrofitting; demonstrate that demographic shifts are demanding different housing options; argue the pressing environmental and energy reasons for retrofitting; present current methods that are being used for retrofitting; and analyze the barriers that need to be addressed if retrofitting is to succeed in North America. This review is of material relevant to retrofitting the suburbs in Canada and the United States and distinguishes between the two when applicable.

2.1.1. Suburbs and Sprawl Defined

Defining what the suburbs are is quite difficult since the characteristics used to define them have varied over time and space (Nicolaides & Wiese, 2006). Despite this difficulty there is enough consensus to explain them and Harris (2004) identifies six common characteristics of the suburbs:

> "1 low density of development, typically of detached, or semi-detached, dwellings
> 2 location at, or close to, the urban fringe
> 3 high level of owner-occupants

> 4 politically distinct
> 5 middle, or upper middle class in character
> 6 exclusively residential, implying that residents must commute beyond the suburb to work"

Not all of these characteristics will be found in all suburbs but Harris (2004) has identified them as generally common and this understanding is considered to be sufficient. In discussing suburban features, Nicolaides and Wiese (2006) identify almost the exact same characteristics as Harris (2004) and also emphasize that there is segregation in the suburbs. But they say that it may be a "segregated diversity." Since there are so many suburbs across North America there is great diversity from suburb to suburb (Baldassare, 1992; Nicolaides & Wiese 2006). The economics of the housing market also ensure a degree of economic segregation from suburb to suburb which in addition to the political segregation results in "share[d] values and life styles" in many suburbs (Martin, 2003). Thus the suburbs have created pockets of relative socio-economic congruence. Of importance for this thesis is that suburbs are segregated economically, socially, and by land use. As well, suburbs are of a lower density and have enough land-use segregation that transportation usually requires a car and is spread out in a way that uses resources and energy in a wasteful manner (Blais, 2011).

Sprawl is a distinct term separate from the suburbs but faces the same challenge in definition. In their review of sprawl Galster et al. (2001) could find no common definition and little in the way of any objective or "operational" definition. Using data on urban areas in the US, Galster et al. (2001) developed a more comprehensive definition for sprawl, defining it as "a pattern of land use in an urban area that exhibits low levels of some combination of eight distinct dimensions". These dimensions include density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. Galster et al. (2001) argue that while a suburb could be considered sprawl by their definition, not all suburbs are necessarily sprawl. This thesis will take care not confuse the two terms, as is often the case (Galster et al. 2001).

2.1.2. Suburban Retrofitting Philosophy and Theory

Retrofitting and Adaptation Defined

In Dunham-Jones and Williamson's 2009 book *Retrofitting the Suburbs,* they detail many cases of retrofitted suburbs and give a definition that they use to define 'suburban retrofitting'. They contend that, "as distinct from infilling, retrofitting involves systemic changes intended to enhance the performance of places". Continuing on this line of reasoning, they contrast infill development by identifying that "intensification and infill of the suburbs directly detracts what it is they offer. This includes stressing schools, transportation and ironically, green space." To sum their message, they want those involved in suburban retrofitting to look at the bigger picture and the *function* of the suburbs themselves and aim to change these aspects. While this is not the only definition of suburban retrofitting, it largely embodies the sprit of how many current planners and city builders view suburban retrofitting and is a common thread throughout retrofitting literature (Tachieva, 2010; Dunham-Jones, 2005; Randall, 2001; Dagenhart, 2008).

Another term used throughout the literature is 'adaptation'. While the term retrofitting is often used for large-scale redevelopments that occur in a relatively short period of time (less than a decade), adaptation has seemed to have found its niche in the smaller scale projects that utilize more incremental change and are generally smaller in scale (Friedman et al., 1998). Adaptation projects generally highlight actions that homeowners can take to make their neighbourhood more resilient and better suited to accommodate internal and external change. These projects are often led by local community or homeowners groups, such as the *First Suburbs Coalition* (Mid-America Regional Council, 2011), or by planning leaders such as Friedman and Krawitz. (2002). In both cases, adaptation is ongoing and does not have a firm completion date. It differs from changes that occur naturally in all suburbs in that there is a guiding plan or vision for the adaptation.

While it is true that both ‘retrofitting’ and ‘adaptation’ embody the same spirit, they will be used to denote larger projects and smaller projects respectively. When a term is needed to embody both retrofitting *and* adaptation, the phrase ‘retrofitting the suburbs’ or ‘suburban retrofitting’ will be used. New Urbanism is often the model used when designing or planning a retrofit (Dunham-Jones & Williamson, 2009). A “complete community” that is walkable, mixed use and pleasant, as is customary the New Urbanist style, can be seen in Figure 2.1.

Figure 2.1: A new urbanist community concept (Duany Plater-Zyberk & Company, 2011)

Suburbs, Neighbourhoods and Community

The concept of community is prevalent in much of the literature that discusses the benefits of suburban retrofitting. Dysfunctional communities are often said to be synonymous with suburban sprawl (Brain, 2008; Friedman, 1998). However, both Friedman et al. (1998) and Brain (2008) argue that many who study New Urbanism, that often advocated as the antidote to sprawl and a model for retrofitting, take for granted that there is a lack of community in the suburbs and that retrofitting or new design is required to create community. Both argue that there is strong community in the suburbs and they do constitute a neighbourhood community. Brain (2005) argues that designing new urbanism communities (or other similar forms) for the sake of environmental and social betterment, with the goal of enhanced "community development" is questionable. This reasoning falls from the Brain's (2005) and Friedman et al.'s (1998) work, that community is often present in the most unlikely places, even in the face of an impeding built environment.

While many new urbanists and sustainable community advocates contend that community is the end goal (Dunham-Jones, 2009; Southworth, 2005), Brain (2005) suggests that what new urbanists and community builders desire is not more community but more civility. Brain argues that community breeds NIMBYism and resistance to change; the exact change that new urbanists and suburban retrofitters are advocating for. He does not denounce the importance of community and built form, but rather suggests the unintentional dubiousness of the current call for community.

Friedman et al. (1998) also suggest that there is not a lack of community in the suburbs, but does argue that suburban design is not conducive to community building. The inadaptability of the suburbs due to zoning bylaws, certain stigmas surrounding 'density', and other factors, create a situation that dampens community building (Friedman et al., 1998). This inadaptability is a common theme for suburban critiques. This is relevant to community development because rather than adapting their home to meet their changing needs, people opt to move out of their community, leaving a void when they go (Chow, 2005; Friedman et al., 1998). This creates a continual migration of people through the neighbourhood community, weakening it in the process.

Similar to Brain's (2005) and Friedman et al.'s (1998) caution on the causal link between built form and social factors, Southworth's 2005 study on the state of walkable community design also questions the causal links between built form and health. There seems to be a link between the two, but it is not certain that it is causal. Thus when retrofitting the suburbs, one should not automatically expect that social benefits will naturally fall out of improved design.

There is good reason that there exists debate over the state of community and neighbourhood in the suburbs. Neighbourhoods and the physical and social infrastructure they support perform important functions for both the residents of a neighbourhood as well as for city cohesion and operation. Neighbourhoods do this by acting as a “mediator” (Scherzer, 1998) or “bridge” (Hise, 2010) between the residents of the neighbourhood and the larger city, allowing citizens to “mesh” (Wellman & Leighton, 1979) with the city.

For the residents it provides a platform for forming local solidarity, neighbourhood pride, formal and informal organizations (local churches, business, associations, etc.) and allows residents to place themselves in the larger picture giving degree of meaning to their lives (Keller, 1968; Hise, 2010; Scherzer, 1998; Knox & Pinch, 2009). The importance of solidarity and neighbourhood pride can be seen when neighbourhood activism fends off outside threats (Martin, 2003) and provides substance to Brain’s (2005) NIMBY argument. In working class (Knox & Pinch, 2009) or ethnic neighbourhoods (Hise, 2010), where economics, class, or culture restrict mobility (or simply for people with physical restrictions on mobility) (Keller, 1968), neighbourhoods provide vital social support connections so residents can function within confined areas, but also to use neighbourly connections to access the larger city. Martin (2003) and Knox and Pinch (2009) argue that neighbourhoods are deterministic when it comes to life changes including, poverty, employment, education, as well as stigmas, self perception and ultimately self-esteem. For the city as a whole, the neighbourhood presents a manageable unit to stage interventions (Hise, 2010), allowing politicians, planners, and academics, a reasonable scale for analysis (Scherzer, 1998).

2.1.3. Demographic and Market Shifts

Historical, Current, and Future Trends

There are significant demographic changes taking place in North America that demand a diversity of homes not currently offered in the market (Nelson, 2006). This is one of the main drivers behind the need to retrofit the suburbs. Currently the suburbs are dominated by single-family homes designed for the nuclear family (Nelson, 2006; Chow, 2005; Harris, 2004). The market for single-family homes was driven in the boom following WWII and the single family home has grown to dominate the North American Market over other forms of housing (Dunham-Jones & Williamson, 2009). Demographics have since shifted and the nuclear family is no longer the dominant household type as households of seniors, singles, and childless couples increase (Nelson, 2006, Urban Land Institute, 2010).

In 1950, fully half of all American households were families compared with about 10% that were single person households. At this time the average household size was 3.4 people. Contrast this with the year 2000 where only a third of households had children and the average household size was 2.5 people. By 2025 only a quarter of households will have children and more than 30% will be single person (Nelson, 2006). Clearly the demographics are different today than in the immediate post-WWII era. This does not indicate that the US housing market will not grow, in fact the US will need about 32 million more homes by 2025 to meet the population's needs (Masnick, Belsky, & Di, 2004). The difference will be the makeup of these households in that approximately a third will be single person, about a third will be childless couples, and a third will be families with children (Masnick, Belsky, & Di, 2004).

In this shift there are two major groups that are going to have arguably the largest influence on the housing market: baby-boomers who are becoming seniors and the echo-boomers (generation Y), the children of the baby-boomers (Doherty & Leinberger, 2010, Dunham-Jones, 2005). These two demographics demand more walkable spaces, by necessity for seniors who often have mobility resrictions and by preference for urban environments by generation Y (Nelson, 2006; Doherty & Leinberger, 2010; Urban Land Institute, 2010, Hodge, 2008).

Seniors, Generation Y, and Demand for Different Housing Types

The large demographic shift that will be occurring in North America over the next few decades is clearly illustrated by the number of people turning 65. The number of Americans turning 65 will increase by about 10 times between 2000 and 2025 (Nelson, 2006). Canada also has a rapidly aging population and the impacts on Canada's housing market has been extensively analyzed in Hodge's 2008 book, *The Geography of Aging,* from which the following statistics on Canada's aging population were taken. In 2001, 12% of Canadians were over 65, 5% higher than the 7% standard set by the United Nations that defines an "aged country" (Hodge, 2008). To get a better picture of the impact this will have on the housing market, some statistics can help but it in perspective. In 2006 Canada had 4.3 million seniors or about 13% of the population. As shown in Table 2.1, the number of Canadian seniors will grow dramatically to between 22.5% and 24.5% of the total population.

Table 2.1: Seniors' Population Range of Forecasts, Canada, 2031 (Statistics Canada, 2005)

Subject of Forecast	Low Forecast	Medium Forecast	High Forecast
Total Canadian population	36,261,200	39,029,400	41,810,800
Total population 65+	8,848,000	9,136,000	9,411,000
Total population 85+	1,068,000	1,121,000	1,184,000
Institutionalized population 65+	654,800	676,100	696,100

As of 2006 for those over 65, 93% live in their own homes, with 70% of them living in a family setting (with a partner or other family). Fully 30% live alone and 7% live in institutions. 71% own their home and the other 29% rent. They have an average income of $30,775 and $19,461 for men and women respectively. Alarmingly, 44% of seniors spend more than 30% on housing, the standard cutoff when housing is taking up too much income and compromises the ability to pay for other necessities. Canadian seniors are a diverse group with fully 27% having emigrated from another country. The number of non-Canadian born seniors will continue to grow, as immigration has continued to grow historically (Hodge, 2008).

Most communities, including the suburbs, are not currently prepared for the surge in seniors (Nelson, 2006; Friedman et al., 1998; Hodge, 2008). The housing stock is severely inadequate in terms of size and accessibility. The fact that a car is required for almost all trips can make the suburbs a very isolating place for seniors with limits on their abilities and access to personal transportation (Hodge, 2008; Urban Land Institute, 2010). Since one third of all seniors live in the suburbs and many want to age in place, that is stay where they raised their family, the suburbs will need retrofitting to meet this demand. Not only is this important for the seniors themselves but also for the larger community as was argued in Section 2.1.2.

When it comes to housing, seniors want the same thing we all do: independence (Hodge, 2008). This independence can be broken down into three factors: health, income, and housing. Affordable and appropriate housing is essential for any person, but seniors often have certain aspects of their lives that demand different housing than is currently available. Since a limited number live in institutions, clearly building more institutional spaces is not the optimal solution in terms of creating enabling environments for seniors (Hodge, 2008).

The assertion that higher-density housing options are truly in demand is further supported by the fact that in the US throughout the current recession, the prices of car-dependent suburban homes lost much of their value but walkable urban places largely did not (Doherty & Leinberger, 2010). In addition to the aging population, the preferences of generation Y are pushing this current demand for multi-family dwellings and denser homes in the US for affordability (Doherty & Leinberger, 2010). There are enough homes on the market right now to satisfy needs, but what is needed are rental apartments and smaller places for seniors and families who can't afford homes (US) and young couples. The problem goes beyond simple affordability and is a result of the demographic structure of potential homeowners. (Urban Land Institute, 2010; Nelson, 2006).

Nelson (2006) predicts that urban and first-tier suburbs will see gentrification as seniors, the elderly, and young professionals with an affinity for density move in. This coupled with rising energy prices and a lower demand for large suburban homes, will push poverty into the outer suburbs. Since fringe homes are generally large, he predicts that these homes would be split to accommodate more people. If this occurs without the proper planning, it could have negative consequences as the suburbs have poor access to transit, social services, and jobs, making it even harder for the impoverished to access necessities. Doherty and Leinberger (2010) reports that in the gated communities of Hemet, LA and Germantown, ML, both of which are suburban fringe developments, the large homes are being converted to boarding houses and rental units for low-income citizens. He also identifies the issue of increasing housing prices in urban and first tier suburbs pushing the impoverished out, but notes that he believes the high prices associated with compact, transit-oriented developments are simply the market response to the fact that this market sector is currently underserved. Brown (2011) adds to the anecdotal evidence of Doherty and Leinberger (2010) with a news report on Californian luxury suburban homes that are being rented out as student housing.

Younger people who are just coming on the market demand denser communities (Nelson, 2006; Urban Land Institute, 2010). They want to move to places with 24-hour activity where things are closer, more convenient, walkable, and less car dependent (Urban Land Institute, 2010). There will be a shift away from the sprawling city fringes and a move to commercial centres. The joint Urban Land Institute and PricewaterhouseCoopers 2011 housing market report indicated the best centers are "coastal gateways" located near global markets. These include cities such as New York, Washington DC, Seattle, San Francisco, and Boston. Vancouver and Toronto will see the highest demand for urban living in all of North America.

Friedman et al. (1998) also aruge that splitting homes into rental units will extend their useful life for older residents. They also highlight the benefits of garden suites for helping senior residents age in place. The garden suite seems to have much to offer but bylaws prohibit them in most North American cities (Friedman et al., 1998). Driven by geographic constraints, the demand for affordable rentals, and a push for sustainability initiatives, Vancouver recently passed a bylaw allowing garden suites or what they call laneway houses as shown in Figure 2.2 (City of Vancouver, 2008).

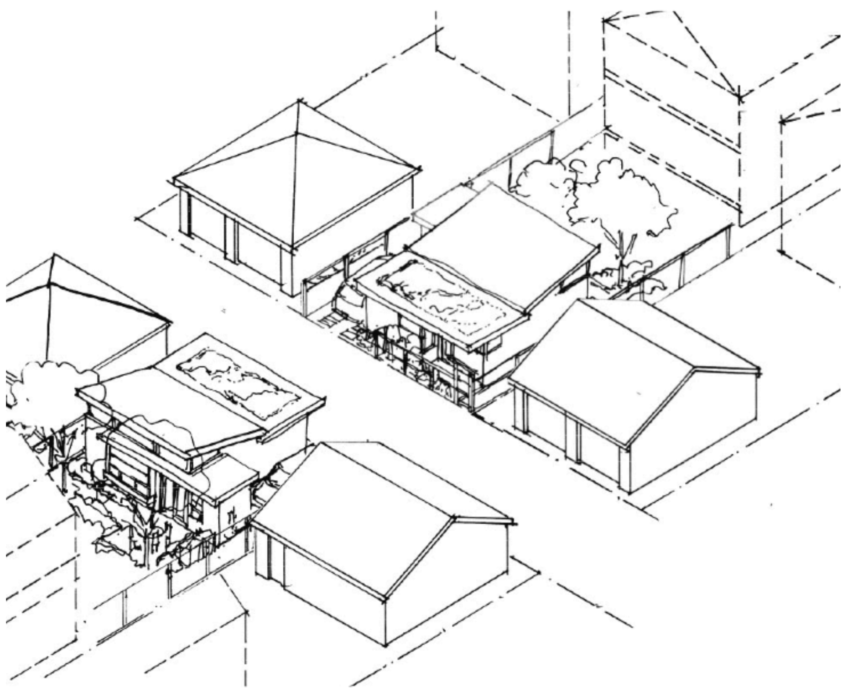


Figure 2.2: Garden suites (City of Vancouver, 2008)

Nelson's 2006 assessment of the current state of suburban housing identified that virtually every city in the US saw some form of suburban decline, and this was before the housing crash in 2008. At the time he argued that the suburbs needed change and those that did not take advantage of opportunities to adapt would fare poorly in the future. Given the state of the housing market in the US in the past several years, his assessment is arguably even more pertinent now. Nelson recently gave a presentation titled *The Coming Housing Calamity* at the *Forum on Land and the Built Environment* in Cambridge, Massachusetts saying that he still predicts the division of homes and that the US is heading for a 'housing calamity' due to the lack of housing types demanded by the market (Steuteville, 2011).

Nelson (2006) has documented quite well the shifting trends of preference to higher density housing. While he notes that the majority still prefer single detached and that surveys saying otherwise can be misleading (what people say is not always what they do), the number of respondents who prefer higher density housing (row, town, apartment, duplex) is not insignificant and the stated preference is in the range of 35 to 40%. Based on his analysis, the current US stock of single detached housing is sufficient to meet demand until 2025 and that the market is currently oversaturated with these homes. He contends that lack of choice for good alternatives has hindered those with preference to higher density homes from self-sorting into such housing. For the first time in recent history the sales of condos and co-ops surpassed that of single detached homes in the US Mid-west and Northeast, clearly indicating the significant market for alternative housing types (Nelson, 2006). Vacant retail, commercial, and industrial buildings will be transformed to accommodate new mixed uses with a focus on residential due to the lack of apartments and multi-family dwellings currently on the market (Urban Land Institute, 2010).

In a Canadian context, the housing market was not hit as hard by the recession and has not seen significant decline (Urban Land Institute, 2010). This does not exempt Canada from the fact that there is still a demographic shift occurring and there will be more demand for more urban and compact niegbourhoods, opening up new markets for multifamily dwellings (Urban Land Institute, 2010; Hodge, 2008.

2.1.4. Geopolitical and Environmental Influences

In addition to the changing demographics there are other factors that that must be considered in the suburban retrofitting process. Two important factors include fuel prices and climate change. The causes of each are largely out of the hands of individual residents as North American governments continues to ignore these issues in terms of effective public policy (Gould, 2010). These two issues are bound together and make for a very uncertain future, especially for the suburbs. A future where municipalities must be proactive in halting the causes of climate change and limiting the impacts of peak oil, but also adapt to manage their inevitable impacts.

Regardless of any mitigation efforts many climate scientists agree that an average of 2^{o}C warming will occur and could very likely hit 4^{o}C by 2100 (Berrang-Ford et al, 2011). This has consequences beyond simply a raise in temperature and will bring changes in weather as well affecting necessities such as food and water availability (Ford et al., 2010). In their review of adaptive actions for climate change, Berrang-Ford et al. (2011) searched for adaptive techniques that were being employed around the world and that have been documented in academic literature. They were able to identify a very limited number of documented cases of actual adaptation (21 in North America), but many cases of *proposed* adaptations. The scale of these adaptations has yet to be investigated and there could be other adaptations that were not explored in academic literature, but documented elsewhere. Nevertheless they note that there does not seem to be adaptation of any real significance occurring in North America. The big challenge they identify is that adaptation will be required to deal with climate change but it is uncertain whether the capacity to adapt will translate into actual adaptation. This lack of adaptation has been attributed to a lack of understanding of our actual vulnerability (Berrag-Ford et al, 2011).

Given that it is uncertain what the exact impacts of climate change will be, it is hard to plan for a future with a different climate (Berang-Ford et al, 2011;

Ford et al, 2010). What has been documented though is that diversity is a key ingredient to successfully adapting and dealing with uncertainty and change in regards to housing (Nelson, 2006; Chow, 2005). It can be concluded then that if a community wants to be resilient, it must become more diverse and self-sufficient to deal with change.

Peak oil is a certainty that will happen in the near future (Rubin, 2009). The repercussions of peak oil will be higher gas and fuel prices, higher food prices, and higher prices for just about everything that relies on petroleum products to produce or ship. Given our society's complex dependence on fossil fuels, the exact impacts are uncertain. Higher prices in fuel mean that improvements to our mass transit systems will be required and biking and walking will further themselves as economically desired modes of transportation, more so than they are now (Southworth, 2005; Dunham-Jones and Williamson, 2009). Rubin (2009) predicts a reverse globalization of sorts as food, daily necessities, and manufactured goods become more economical to produce locally as fuel costs trump labour costs as the dominant cost of production. This becomes important when remembering that the suburbs require large amounts of cheap fossil fuels to operate (Blais, 2011) and could become economically unviable if they remain dependent on cheap oil and are left disconnected from resilient sources for daily necessities (Burchell et al, 2005; Rubin 2009).

A future of higher energy prices, peak oil, and climate change is certain, but the exact impacts are not. So if the suburbs (and other types of communities for that matter) are to be viable places to live, they must adapt and become more resilient.

2.1.5. Current State of Retrofitting

Benefits: The Creation of Resilient Communities

There are many benefits that can be gained from retrofitting the suburbs if done properly. They include environmental protection, increased "community capital", resilience within the community and economic gains for the parties involved. Callaghan and Colton (2008) argue that resilience should be the primary goal for communities wishing to achieve long-term sustainability as resilience presents itself as a middle ground between short-term thinking and the daunting task of long-term sustainability. For them "resilient communities are those that are able to absorb and/or adapt quickly to change and crisis" and they are made up of six types of community capital: environmental capital, human capital, social capital, cultural capital, public structural capital, and commercial capital. These sources of capital are arranged in a hierarchal way such that each one is dependent on the one before it, with environmental capital forming the base from which all other capital flows. The following section outlines some of the important aspects of resilient communities relevant to this thesis.

The suburbs use extensive amounts of land, often encroaching on farmland and ecological systems that are important to local environmental health (Burchell et al. 2005). They depend on large amounts of energy for transportation, public infrastrcutre, and heating purposes that in turn create pollution and greenhouse gases (Burchell et al., 2005). Virtually all retrofits that have been proposed in the literature involve using resources and energy in a more efficient manner (Tacheiva, 2010; Dunham-Jones and Willaimson, 2009). Higher density designs mean that less land is being used up because more people can be housed on less land. It also means that places in the community are physically closer together, making transit, walking and biking (which all use less energy than personal cars) more viable. For this reason Southworth (2005) claims that walking is the basis for the sustainable city. Walking is known to be a healthier alternative to driving and some studies suggest that a walkable community is also a healthier community with increased social capital (Southworth, 2005; Leyden, 2003). As mentioned, there are some questions regarding the causal link between health, obesity, and neighbourhood design, but studies still do point in this direction (Brain, 2005, Leyden, 2003). No studies have seemed to suggest that walkable communities have inherent systemic negative heath consequences, as are found in the suburbs (Brain, 2005; Leyden, 2003; Southworth, 2005).

Denser communities have been shown in some studies to increase the social capital of a community (Leydon, 2003). This includes the level of human integration, civility, community engagement, and culture found in a community (Leydon, 2003). Many of these are the result of residents simply being able to walk instead of drive. Walking is the most equitable and accessible form of transportation; it creates increased social interaction, and has been shown to have positive metal and physical health effects (Southworth, 2005, Leyden, 2003). So while the causal link may still be contentious, there is no doubt that the design of a denser community is conducive to the social, physical, and mental health of a community (Southworth, 2005; Leydon, 2003; Friedman, 1998; Brain, 2008).

From a financial perspective, the retrofitting of the suburbs can be very beneficial to all those involved: residents, developers, the municipality, and local retail and business owners. As previously mentioned, virtually every major US city has seen some sort of decline in the suburbs and this decline can be translated into an economic cost (Nelson, 2006; Burchell et al. 2005). The fear of possible blight in their community and the thought of their home losing value can cause citizens to react (Chow, 2005; Dunham-Jones & Williamson, 2009). Municipalities also see that a down-and-out neighbourhood will become a burden on the city's budget rather than a boon (Dunham-Jones, 2009). Commercial property owners are also seeing that once prominent regional suburban malls are falling victim to larger power-centres and are having trouble maintaining tenants (Urban Land Institute, 2010; Dunham-Jones and Williamson, 2009). These three stakeholders, residents, municipalities, and commercial property owners are realizing that retrofitting the suburbs is required to stay relevant and commercially viable. Large retrofits can provide municipalities with increased tax revenue, retail is seeing higher than average sales in mixed-use developments, and property owners are benefitting from an increase in value of their real estate assets

(Dunham-Jones and Willamson, 2009; Urban Land Institue, 2010; Curic & Bunting, 2006). As Dunham-Jones and Williamson (2009) argue, the suburbs were originally built for the benefit of the individual, not for the benefit of the community, region, or city. When times were prosperous, sprawl and higher energy prices did not choke the economic viability of regions and the community saw some benefits. However, now that sprawl has surpassed a critical point in many areas, suburbanites are learning that the individual gains from suburban living are largely negated if not reversed if the community and region are not economically and socially viable as well (Dunham-Jones and Williamson, 2009).

What has been demonstrated numerous times is that diversity, including an array of housing options for multiple different markets and architectural designs capable of change, are required if a community is to be able to adapt to external and internal change. (Nelson, 2006; Chow, 2005; Friedman, 1998). This lack of diversity in suburban design, limited by archaic and restrictive bylaws, diminishes the resilience of a community and can actually facilitate blight (Nelson, 2006). Not only does the physical form of the suburbs need to be retrofitted, but the laws that govern them as well. Retrofits allow for designers to adapt old spaces, but also plan new spaces for future adaptability. Thus retrofitting increasing the resilience and future viability of the community (Friedman, 1998; Dunham-Jones and Williamson, 2009).

Types of Suburban Retrofits

There are many different types of suburban retrofits and experts have different opinions on what makes a good retrofit. At one end of the spectrum there are large-scale retrofits where large portions of old suburban infrastructure, such as a large decaying mall and the surrounding area, are completely transformed in a short period of time. On the other end of the spectrum there are smaller-scale neighbourhood adaptations that occur gradually over time, often focused on maintaining the ‘character’ of a neighbourhood, while allowing for gradual change. There is also the notion of reverting portions of the suburbs back to agricultural or open-space land as is being done in Detroit, MI and Youngstown, OH.

In their 2009 book *Retrofitting Suburbia* Dunham-Jones and Williamson advocate for large-scale suburban transformation, largely in the form of mall retrofits. They contend that large retrofits are the only way that retrofitting can have an impact and that smaller retrofits simply do not have the transformative capacity to create the required change. Their book documents case after case where a decaying and declining mall and a few surrounding properties have been retrofitted into a mixed use, new urbanism style design. Figure 2.3 and Figure 2.4 show the retrofitting of the decaying Cottonwood mall in Salt Lake City, Utah in the New Urbanist style. With mall properties, there are relatively few landowners but large parcels of land that can be more easily obtained for large retrofits.

Friedman et al. (1998) and Friedman and Krawitz (2002) have looked at retrofitting suburban communities from a smaller scale. They contend that a smaller retrofit, facilitated by form-based bylaws and design support tools for community residents will allow the housing stock to transform and adapt to people's needs. Large "wholesale" retrofits can damage the character of existing neighbourhoods and have negative consequences. Community building components such as garden suites, improving the pedestrian experience, form-based bylaws, and maintaining the character of the neighbourhood through context-based design codes can allow the community to adapt to change, rather than stagnate and decay (Friedman et al., 1998).

While Friedman et al. (1998) and Dunham-Jones and Williamson (2009) differ in their approach to retrofitting, they concur with many other planners that the retrofit must be location and community specific (Dagenhart, 2008; Churchill & Baetz, 1999). Rather than pit large-scale retrofits against small-scale retrofits, it can be seen that each has their own place in the large scheme of suburban retrofitting and that local context often plays a dominant role in the final design.

Figure 2.3: Before mall retrofit – Dunham-Jones & Williamson, 2009; Courtesy Duany Plater-Zyberk & Co.)

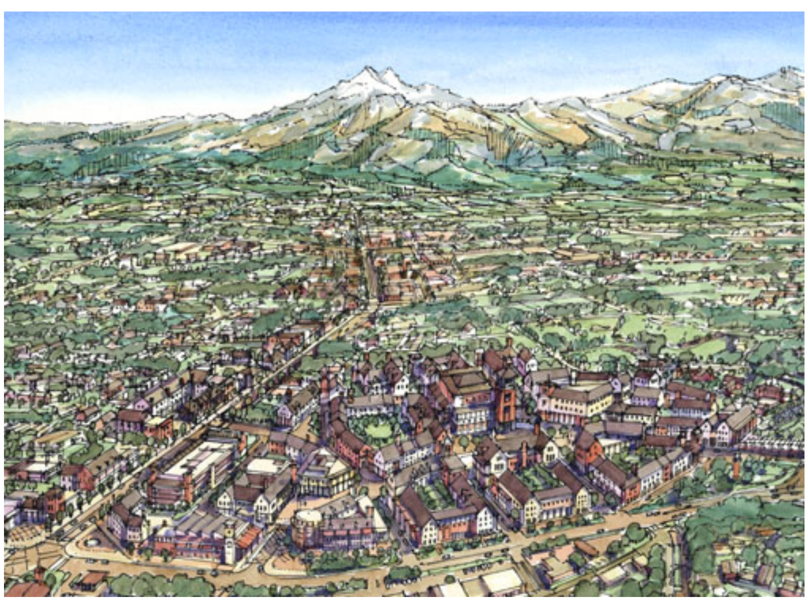


Figure 2.4: After mall retrofit (Dunham-Jones & Williamson, 2009; Courtesy Duany Plater-Zyberk & Co.)

Tacheiva (2010) proposes a basic decision support system (DSS) that is a checklist of sorts for determining a suburb's viability to be retrofitted. Depending on the outcome of this DSS a suburb would either be eligible for retrofit, left alone, or dismantled and turned back into agricultural or open-space land.

There are certain aspects that seem to produce little disagreement across the literature and the most ubiquitous sentiment is that the pedestrian always comes first in sustainable transportation planning (Sothworth, 2005). Since WWII biking and walking were seen as largely recreational activities in North America but recently, perceptions have shifted and they are now seen as legitimate forms of transport (Southworh, 2005). There are few who disagree that effective connectivity both within the community as well as connecting the community to other areas in the region is a necessity for a successful retrofit (Cervero, 2002; Cervero & Kockelman, 1996; Dunham-Jones & Williamson, 2009; Nelson, 2006). It has been established, especially for large-scale retrofits, that the area must have good transit connections to the larger region if car use is to decline. A superior pedestrian network will allow citizens to transfer from one mode of transportation to the other with relative ease and there should be minimal interruptions in the travel (Southworth, 2005). The "pedestrian pockets" that are often formed after a large retrofit are not sufficient to increase the modal split in local community if they are cut off from the larger region (Cervero, 2002; Cervero & Kockelman, 1996, Hodge, 2008). While this may pose constraints on some suburban retrofits, there are a number of suburbs in the US within cities that could be retrofitted that are also along a rail line that would allow for effective public transit (Nelson, 2006).

The car is still the dominant form in many cities and this is evident when looking at studies that advocate for improved pedestrian connectivity. Few, if any, suburban retrofitting advocates suggest, the major re-routing of roads (save for large mall retrofits) and some even suggest that pedestrian overpasses are a potential solution (Southworth, 2005; Randall and Baetz, 2001). There is the anticipation that cul-de-sacs will eventually be connected to improve mobility in the suburbs, but few have been connected thus far (Dunham-Jones and Williamson, 2009: Nelson, 2006; Tachieva, 2010).

It has been shown by Cervero (2002) and Cervero and Kockelman (1996), that there is no single factor that will lead to increased modal split, but that design, density, and diversity are important. They contend that it is important to realize that it is the synergies between multiple aspects of a community that will increase pedestrian trips.

The last major point of agreement is that established land uses, particularly road structure and major arterials, set the stage for future land use (Southworth, 2005; Dunham-Jones & Williamson, 2009; Friedman et al, 1998). There are opportunities to address the negatives associated with these established land uses through retrofitting, but persistence and creativity will be needed if the barriers of established land use are to be overcome and suitable design, density, and diversity fostered in the suburbs (Dagenhart, 2008).

2.1.6. Barriers and Adaptive Tools

While shifting demographics, energy price increases, and environmental change have set the stage for suburban retrofitting, there still remain several barriers. The three main issues found in this review are systemic in nature and difficult to change. First the physical makeup and form of the suburbs and people's affinity to this form create a barrier to change. Second, there are financial barriers and incentives to not alter the current suburban form that are purely a product of the current real estate market. Lastly are bylaws that are outdated and not suited to allow for adaptability.

Physical Structure and Resistance to Change

As previously mentioned one of the largest barriers to effective retrofits is the fact that existing land structure is often fixed for the long term and established land uses set the stage for further retrofitting (Southworth, 2005; Dunham-Jones

& Williamson, 2009) Not only are land uses often fixed for the long term, they are often split among many individual owners. Small land parcels and many individual landowners make large retrofits virtually impossible and even minor adaptations very difficult (Baetz, 1994; Curic & Bunting, 2006; Dunham-Jones & Williamson, 2009). Each property wants to develop for their own economic gain and a municipality's choice to allow one area to be developed over another leads to a sentiment of unfairness among landowners. To solve this problem municipalities often allow individual landowners to develop as they wish but at the expense of ecological and social health of the larger community (Baetz, 1994). To solve the above dilemma, there are a few methods proposed. One would be to form landowner compacts (Ardendt, 1994). The concept of landowner compacts described by Baetz (1994), while used for fringe development, is akin to the methods used in case studies presented by Dunham-Jones and Williamson (2009). Landowners come together, effectively pool their land, and divide the benefits from development equitably. This type of cooperation is certainly applicable to the retrofitting of suburbs where there are multiple landowners, each wishing to maximize their own profit.

An example of this in practice is described by Sherman (2005) who reports how a suburban homeowner was able to bring several suburban landowners together to build a wiffle ball field on several parcels of private property. The field was constructed by negotiating a set of rules that all the participating landowners could agree to.

When dealing with multiple developers, municipalities and planners can attempt to coerce developers into planning their sites so they complement each other. This can be seen in the redevelopment of the retrofitting project for the Downtown Kendall Urban Centre District in Miami-Dade County (Dunham-Jones, & Williamson, 2009). Landowners had to maintain a 15% open-space requirement in this development, but there was the risk that these open spaces would end up as fragmented pockets and not as effective public spaces. To get developers to pool these open spaces into larger public squares, each open space had to be anchored to a focal point, but landowners could combine their open spaces onto one focal point. This sharing resulted in larger green spaces and parks than would otherwise have been built (Dunham-Jones & Williamson, 2009). While this is a specific case, it is evident how bylaws can be used to allow for collaboration between developers.

At the residential level when dealing with individual landowners, participatory approaches (public consultation) for stakeholder input in the planning retrofitting process is seen as more socially sustainable. However, residents often have unrealistic expectations on the weight their input carries and will only engage in the process when they have a tangible interest (Curic & Bunting, 2006). Also, what works in one neighbourhood will not always work in another neighbourhood when it comes to retrofitting (Curic & Bunting, 2006). Landowners need to be able to see the benefits for them for potential development if they are to be actively engaged in a meaningful way (Curic & Bunting, 2006).

Curic and Bunting (2006) explored the NIMBYism associated with the intensification of hydro corridor lands in Toronto. These vacant lands, as they identified, were excellent opportunities to retrofit and amend a large portion of a largely suburban landscape while making sure that the new land uses were compatible with existing land uses in the area. Curic and Bunting (2006) found that the local residents were largely opposed to building on these lands, especially anything that was different from the existing neighbourhoods. It was found that the residents understood ‘compatible’ to mean ‘the same’. They were concerned that the new homes, that were to be of a higher density than the surrounding suburb, would bring blight and depressed property values because a lower social class would move in. They argued the loss of greenspace in place of social blight because it would have been taboo to discriminate based on social class. This classic case ended up being a significant political issue and certainly provides more backup to Brain's (2005) argument that tight-knit community can create NIMBY attitudes.

Brain (2005) demonstrates that this phenomenon could have been about more than just land value and green space. He says:

> "the importance of our relationships to stable places as part of the fulfillment of developmental needs at both ends of the life span. Attachment to particular places has been shown to be a very important part of cognitive, emotional, and moral development of individuals in modern society... Recent research has shown the importance of place as a medium in which we maintain our sense of ourselves and our orientation in the world as we age."

Randall (2008) also makes sense of why people may fear a change from the suburban norm. In a study of housing preferences he showed that one's housing preference is heavily influenced by their current housing situation. That is, those in higher-density housing are more likely to accept higher densities than those in the low-density single detached homes.

History has also instilled ideals of the suburbs, forming the mental construct for what the suburb should and should not be (Nicolaides & Wiese, 2006). Suburbs *represent* the ideal living conditions, regardless of how well they meet this ideal in reality (Purcell, 2001). They were the reward for fighting WWII and they represented (and still do represent) upward mobility (Nicolaides & Wiese, 2006) This realization of the suburban ideal, the choice to live in the suburbs, is about more than just aesthetics or the physical nature of the suburbs, it is about the moral superiority of the suburbs over the city (Baumgartner, 1988). The US homeownership programs went a long way in laying the framework for this ideal when the programs promoted home ownership for only the white middle class, helping label the suburbs as good and the city as bad (Nicolaides & Wiese, 2006). As Lang (2005) argues, suburbanites will often revolt against anything that seems even a little bit urban leading to community activism or Brain's (2005) NIMBY.

Many of the cases have so far discussed the barriers at the community level, but what about the homes themselves? There are significant physical barriers to retrofitting the suburban home itself. Over time suburban homes have lent themselves less and less to renovations as the designs of homes made room functions more specialized. Chow (2005) describes why suburban homes have become harder to retrofit over the years since their inception, post WWII:

> "Since Levittown, much suburban development has been based on the idea of a model home. A developer first identifies a market, then defines its life- styles, then programs spaces to meet them. Along the way, normative assumptions direct the design of spaces—their sizes, configurations and adjacencies. In this programmatically driven process, each assumption about a way of living increases the specificity of spaces for prescribed activities. This is not to say that other activities cannot take place within a space, but the potential for other uses diminishes as it becomes increasingly difficult to use specialized layouts in ways other than intended in the initial design."

Chow (2005) also points out that additions have also become relatively harder to accomplish due to shrinking lot sizes and increasing house sizes. Levittown had house coverage of approximately 12.5% of the lot area whereas newer developments are approximately 40% with some trending to 50% (Chow, 2005).

Financial

There are a number of financial barriers that stand in the way of retrofitting. This goes back to the fact that homes are often the largest source of equity for many North Americans (Chow, 2005). Through polices in both the US and Canada, home ownership has been heavily promoted (Nicolaides & Wiese, 2006). Consequently many North Americans have a great deal invested in their homes (Harris, 2004; Grant 2006; Purcell, 2001). This reinforces the individualistic approach that many take in protecting their investment that may come at the expense of the community as a whole (Chow, 2005). In a market system it certainly makes sense to protect an investment but it must be recognized that this has created a barrier to sustainable development (Chow, 2005; Leinberger, 2005).

Nelson (2006) and Dunham-Jones and Williamson (2009) have also identified current and past home ownership policies as well as the large financial investment in one's home as a barrier. But it can be overcome when homeowners see the benefits of adapting, changing, and possibly retrofitting; an example being the *First Suburbs Coalition* in Missouri and Kansas set up to fight blight (Mid-America Regional Council, 2012). The same NIMBY issues that Curic and Bunting (2006) demonstrated can also be channeled to promote retrofitting: when homeowners see the threat of blight in their neighbourhood, they take action (Nelson, 2006; Mid-America Regional Council, 2012).

In addition to personal financial protectionism, the financing system that is used for development is not suited to finance mixed-use development. In his 2005 article Leinberger argues that if we are to retrofit the suburbs then we need to retrofit the financing system as well. He identifies that there are 19 standard real estate products that lenders and financiers will easily provide loans for. These 19 products have been largely developed and tested over the past 50-60 years after WWII in the height of the suburban boom. All 19 products are components of a suburb; hence, none are mixed-use. This system means that the suburban form is not only entrenched in the bylaws, but in the financial system as well. If developers want financing for retrofit projects of a mixed-use nature, financiers demand a higher return for the perceived risk. This often precludes this type of development before it can even be explored.

To overcome the issues with financing, not only could new financial products be created but it has been shown on multiple projects that tax incentives or breaks negotiated with the local municipality can help lift larger projects into a financially viable area (Nelson, 2006; Dunham-Jones & Williamson, 2009; Leinberger, 2005). Blais (2011) argues that the current system used to price development in urban areas favours low-density development through inherent subsidies. She uses multiple instances where average pricing is used over the actual cost of individual developments leading to high-density development paying more for development and low-density paying less.

Bylaws

Allowing variances and bylaws that are fine-grained enough to allow for positive adaptability and retrofitting to occur will be a large challenge for the suburbs. Current bylaws are too coarse for effective retrofits and location-specific adaptations (Chow, 2005, Friedman et al, 1998). Zoning bylaws were initially created to stop incompatible land uses from abutting (eg. a hog rendering plant next to a residential neighbourhood), but some argue that they have gone too far as these threats are no longer present (Nelson, 2006).

Progressive zoning laws such as form-based codes and reworking or removing outdated bylaws allows for flexibility and mixed use while keeping development in the intended spirit of the neighbourhood (Nelson, 2006; Dunham-Jones & Williamson, 2009). This would allow for greater mixed use opportunities such as allowing people to work at home and facilitating the adaptation of the physical form of the suburbs to a more useful form for future residents (Friedman et al, 1998).

New zoning needs to be respectful of the location. It should not be a predetermined set of plans that are imposed in the same fashion on all suburbs. Some suburbs are healthy, and aggressive bylaws that open the door for all sorts of uses are not required (Friedman et al, 1998). In this manner Friedman et al. (1998) borrow from Alexander's *A New Theory of Urban Design (1987),* echoing that growth should be: piecemeal, unpredictable, coherent, and create a depth of feeling.

The need for change in the suburbs is clear and there are many different areas where that change will be needed. At the house level there are tools and benchmarks available for building sustainable or resilient houses. Green building rating systems or standards are models that can be used to ensure a home is built with a certain degree of sustainability. The next section outlines some of the applicable rating systems that could possibly be used at the house level to build resilient homes.

2.2. GREEN BUILDING CERTIFICATION SYSTEMS FOR RESIDENTIAL APPLICATIONS

2.2.1. The Living Building Challenge (LBC)

The Living Building Challenge is the most rigorous of all "green building" certification systems (Canada Green Building Council, n.d.). The International Living Future Institute (ILFI) (2010) the organization that administers the Living Building Challenge (LBC) along with the Cascadia Green Building Council (CGBC) sums up the LBC as

> "a philosophy, advocacy platform and certification program… because it defines priorities on both a technical level and as a set of core values, it is engaging the broader building industry in the deep conversations required to truly understand how to solve problems rather than shift them."

The LBC is heavily focused on building in the spirit of restoring, maintaining, and enhancing the relationship that we as a society have with nature and each other (McLennan & Brukman, 2010). It works on the notion that current societal practices are inherently destructive and that cosmetic solutions are not sufficient to meet the requirement of a total system change (ILFI, 2010).

The LBC can be applied to any project, large or small, including: single buildings, renovations, neigbourhoods, campuses, parks and natural spaces, and private or public buildings (ILFI, 2010). Being performance-based (also called outcome-based), the LBC is made up of 20 "imperatives" that must be met in order to meet Living Building Challenge. To ensure that all imperatives are met, the building is monitored for 12 months after construction (McLennan & Brukman, 2010). Each imperative falls under one of 7 categories: Site, Water, Energy, Health, Materials, Equity, and Beauty. For the full list of the 20 imperatives please see *Living Building Challenge 2.0: A Visionary Path to a Restorative Future* (McLennan & Brukman, 2010).

These 7 categories are called "petals", playing off of the ILFI's symbol the dandelion, as seen in Figure 2.5. A project may gain "petal recognition" but not certification if it can meet the imperatives in at least three of the 7 categories, with at least one of the three categories being Water, Energy and/or Materials (ILFI, 2010). McLennan and Brukman (2010) indicate that the LBC, while very strict, is not unreasonable and there are exemptions made based on the context and current circumstances of a project. For example, the *urban agriculture* imperative that falls under the Site category is waived for renovation projects due to the site limitations that are often present with renovation projects. The LBC also considers that projects may not be able to meet certain "imperatives" based on market conditions and if sufficient evidence is shown that this is the case, an "imperative" can again be waived. Unique to the LBC is a strategy they call "scale jumping", where projects may play off of resources outside of the project boundary. For example, the Net Zero Water imperative can go beyond the project boundary by using surrounding buildings or resources, if approved by the ILFI (McLennan & Brukman, 2010).

Since the LBC is a philosophy and all the imperatives must be met for certification, there is low risk of a project becoming certified without meeting the spirit of the LBC. This has been noted as an issue with other certification systems such as Canada Green Building Council's (CaGBC) Leadership in Energy and Environmental Design (LEED) rating system (Scofield, 2009). The LBC is recognized by the CaGBC as distinct from LEED and is not seen as a LEED competitor (ILFI, 2010).

(a) (b)

Figure 2.5: The International Living Futures Institute logo (formerly the living building institute) (a) and the Living Building Challenge 2.0 Logo (b) (McLennan & Brukman, 2010).

2.2.2. Leadership in Energy and Environmental Design

The *Leadership in Energy and Environmental Design Green Building Rating System* (LEED) is the leading green building rating system in North America and was developed by the United States Green Building Council (USGBC). It was later adapted for use in Canada by the CaGBC (Scofield, 2009; CaGBC, n.d.). The motivation behind its conception was to create a comprehensive rating system for green buildings of all types, from large institutional buildings to single family homes to neighbourhood design (CaGBC, n.d.). The LEED system uses a series of points to award buildings a rating based on how many LEED criteria they meet (CaGBC, 2009).

The LEED rating system most relevant to the construction of residential homes is *LEED Canada for Homes.* This LEED rating system provides a national consistency for the home building industry, allowing homebuilders to construct homes to an agreed upon standard that is readily and recognizable to potential homebuyers across Canada (CaGBC, 2009). *LEED Canada for Homes* has 136 possible points in its rating system, 19 of which are mandatory "prerequisites" (CaGBC, 2009). There is an extensive list of prescriptive measures outlined to obtain the 136 points, but exceptions are given if the builder and design team can prove that the spirit of a point has been met through alternative means. The LEED system uses an input-based rating system where builders pick from a list of green options they want to incorporate into the home and are awarded points in the process. This is the largest systematic difference between LEED and the LBC (CaGBC, 2009; McLennan & Brukman, 2010).

Table 2.2 shows the point and rating system breakdown for *LEED Canada for Homes 2009.* Further details about *LEED Canada for Homes* can be found in the CaGBC guide *LEED Canada for Homes 2009* (CaGBC, 2009).

Table 2.2: LEED Point Allocation and Certification Levels (CaGBC, 2009)

Credit Category	Point Allocation
Innovation and Design Process	11
Linkages and Location	10
Sustainable Sites	22
Water Efficiency	15
Energy and Atmosphere	38
Materials and Resources	16
Indoor Environmental Quality	21
Awareness and Education	3
Total	**136**

Certification Level	Points Required
Certified	45-59
Silver	60-74
Gold	75-89
Platinum	90-136

Being the leading and most prevalent green building rating system in North America, LEED has been subject to a number of criticisms, with the main ones being the lack of monitoring, the input-based approach, and the weighting of points. Many LEED buildings lack ongoing monitoring and hence a responsive system to ensure they maintain their environmental performance. Some studies have concluded that as a result, some LEED buildings actually use more energy and that there is no statistical basis to claim they are more energy-efficient than conventional buildings (Scofield, 2009; Newsham, Mancini, & Birt, 2009). The input based approach is inherently contested by the LBC in their assertion that outcome or performance based rating systems are superior to input based rating systems for green building (McLennan & Brukman, 2010). An outcome-based approach is able to address the issue of continual monitoring. The final common criticism is that the points are disproportionally weighted so easily obtainable points, installing bike racks for a few hundred dollars for example, may be worth the same as upgrading to a more efficient HVAC system for hundreds of thousands of dollars (Scofield, 2009).

2.2.3. Other Residential Green Building Certification Systems

EnergyStar and R2000

Run by the Government of Canada through Natural Resources Canada (2010), these two certifications are given to homes that meet certain energy and water efficiency standards. These homes are generally 30% more energy efficient than conventional homes and must be built by certified builders and tested by a third party to ensure they meet standards. These systems can be applied to existing homes as well new construction (Natural Resources Canada, 2010).

BuiltGreen

The BuiltGreen program is a Canadian certification program for residential homes that uses a point system similar to LEED (BuiltGreen, 2011). The website gives relatively little information on the program but it seems to focus largely on the reduction of energy use with secondary foci on water and resource use reduction, quality construction, and healthier indoor air quality. The system seems to be an attractive economic alternative to other rating systems such as LEED because it has cheaper fees and certification seems to be less rigorous. While building in the manner advocated by BuiltGreen no doubt saves energy and resources, in the context of the real change that is required from the building industry for environmental change BuiltGreen appears to be what McLennand and Brukman (2010) would call a cosmetic solution.

Passivhaus

This certification system is purely about reducing space heating requirements and improving indoor air quality through proper ventilation and heat exchange. The core requirement for Passivhaus is that energy required for space heating must not exceed 15kWh/m^2 and can be applied to residential and non-residential buildings. This system was originally devised in Germany but has spread to many other parts of the world (Bre, 2011).

Providing real solutions to the challenges imposed on the suburbs by demographic shifts, peak oil, climate change, and economics are becoming increasingly important. Counteracting the environmental burden and social deficiency the suburbs impose on the community is necessary, as has been demonstrated. It is clear that there is currently a well-developed overarching theory as to how the suburbs should be retrofitted. According to the experts above, the keys lie in design, diversity, and density, increasing civility, retrofitting the regulatory and financial frameworks that govern the suburbs, and completing and documenting successful suburban retrofits. Well-developed certification schemes give guidance to builders who want to build green, although there is a significant difference between the most and least rigorous certification systems. There is however underdeveloped components of suburban retrofitting that must be investigated to have this practice advanced further. The next section proposes work that could further the agenda of creating resilient suburban communities through retrofitting.

2.3. AREAS FOR FURTHER WORK

Further work is needed both academic and political spheres. Academics and practicing planners must put forth well-developed specifics for suburban retrofitting. Politically, there are opportunities for the development of bylaws that allow for adaptation. Many current bylaws are unsuitable to meet future needs and in fact could hinder prosperity in the suburbs. Programs that incentivize retrofitting where applicable could also be a preventative measure to blight.

Lack of awareness and the uncertainty involved with climate change and peak oil means that there are few practical examples to draw on and little pressure for regulatory change. Community groups and governments could work together to increase the resilience of the suburbs to create physical examples to that can be adapted and learned from in the future.

Financially there is a lack of support for retrofit projects, despite market trends that would support this development. Solid business plans coupled with good community designs are lacking when it comes to retrofitting communities and provide an opportunity for interdisciplinary collaboration between business and planning at both the academic and commercial levels.

Large-scale retrofits have been documented well and implemented successfully in many places, however retrofits of single-detached suburban homes within a community context have barely been breached. This is arguably the largest gap that must be filled in suburban retrofitting. While individual homeowners can make their homes more resilient, there is a still a poor connection between the home and the community in retrofitting practice. There are certainly many aspects of their homes people can change but the sheer volume of possibilities and the lack of guiding policy hindered by outdated bylaws is a significant barrier to suburban retrofitting. The intimate relationship that people have with their home and the large investment many have made in home ownership make the suburban home an important space to "get right" (Brain, 2008; Chow, 2005).

In addition to the connection people have with their homes, a large portion of suburban land use is dedicated to the single-detached home. If solutions to sprawl are to be effective, they must address the suburban home and come to grips with the fact that we cannot just abandon the suburbs. Given the current lack of adequate housing, leveling the suburbs and starting all over is unrealistic, not to mention the huge resources that would be needed to replace them with appropriate housing. While other areas of suburban retrofitting do need work, the connection between the suburban home and the larger community fabric is arguably one of the most pressing issues.

Tacheiva's 2010 book *Sprawl Repair Manual* provides an excellent framework for the practical aspects of retrofitting. She proposes retrofit strategies from the regional scale down to the building scale and includes both basic design aspects as well as a rudimentary regulatory framework for retrofitting. Her analysis is not location-specific and can be used anywhere. She provides a simplistic example of how to retrofit a large suburban home into a space appropriate for students or seniors, or into multiple apartments. However she does not provide many details and her proposal is meant to spark ideas, not as a comprehensive guide to dividing homes.

This idea of dividing large suburban homes into multi-family dwellings is backed up by Friedman et al. (1998), Nelson (2006) and Doherty and Leinberger (2010). These planners and academics believe dividing single-family suburban homes in a market oversaturated with them could solve a number of problems. The fact that this has yet to be done in any meaningful way provides an opportunity to propose some new ideas for suburban retrofitting at the level of the single-detached home. A logical step to include while dividing homes would be to incorporate green building strategies that help homeowners reduce their environmental foot print, making their homes more resilient in the process. The next chapter outlines a conceptual model for a decision support system (DSS) that could be used by homeowners or contractors when retrofitting or renovating a suburban home. It will incorporate both dividing homes as well as reducing the environmental footprint of a home into an integrated tool that can provide homeowners or contractors with the knowledge to make good choices about the future use and function of suburban homes.

3. DECISION SUPPORT SYSTEM: CONCEPTUAL DEVELOPMENT

3.1. WHAT IS A DECISION SUPPORT SYSTEM?

In general a decision support system (DSS) is a tool that aids a user of the system in making choices (decisions) in a given situation. The situation or system in question can be complex (comprehensive home energy management) or simple (siting a garden). DSS users are often non-experts in the field and require the assistance of a DSS *or* the system in question is too complex for even an expert to compute mentally and the aid of a DSS is required, analogous to an accounting system. The DSS itself can be quite simple, such as a series of questions with corresponding scores, or complex, such as using detailed user inputs and complicated algorithms to generate an output. The inputs can be qualitative or quantitative while the outputs are generally in the form of information that allows the user to make choices based on that information. The platform of the DSS can vary such as being software-based or paper-based.

The DSS developed in this thesis is geared to non-experts in suburban home design, resiliency, and environmental impact. It aids suburban homeowners (and their contractors) in making choices about retrofitting their home. While it has been geared to non-experts, people knowledgeable in these areas will find certain aspects of the DSS useful guides or expedient tools for design calculations. Microsoft Excel was chosen as the DSS platform since this program is widely available and understood yet powerful and versatile enough to handle the computing and graphic user interface required for this application. This chapter (Chapter 3) develops the DSS generally while Chapter 4 documents the development of the DSS in detail. Through these chapters it becomes clear how this particular DSS has been structured. Chapter 5 applies the DSS to three example houses to demonstrate how this DSS would be used, including inputs and outputs, as well as it capabilities.

3.2. ASPECTS ADDRESSED BY THE DECISION SUPPORT SYSTEM

The literature review shows a need for change in both new housing development as well as adaptation measures for the existing suburbs and suburban housing stock. There are well-established models for sustainable development of new housing developments (for example see Rees and Roseland (1991) or Churchill and Baetz (1999)), but there are few tools to address adaptation measures for use by homeowners. Adaptation measures are needed to make suburban homes and communities more resilient. The DSS developed in this research addresses this need by creating a tool homeowners can use to make adaptation choices about their home that go beyond cosmetic strategies.

Land ownership in the suburbs is divided among many small land-owners. This makes coordinated wholesale efforts for change both difficult (Baetz, 1994) and likely unwanted (Freidman et al, 1998). Thus, the tool must empower individual homeowners, who are non-experts in home design, energy management, environmental impacts, in addition to other important aspects of community resilience, to adapt their homes. Thus the tool should be easy to use and address multiple aspects of resiliency at the homeowner level. It should also be integrated so that homeowners can be introduced to different aspects of retrofitting or combine multiple retrofitting measures while catering to their particular circumstance. This DSS will also provide a starting point for the further development of user-friendly tools aimed at suburban adaptation. The following sections outline the development of this DSS. This DSS will be made to be as widely applicable as possible to North American suburban homes, but it will not identify suburbs that should be targeted for retrofitting. This is considered beyond the scope of this DSS. Tachieva (2010) has creating a tool that can identify suburbs that are ripe for retrofitting but it has not been widely applied.

The literature review demonstrates that a tool beneficial to homeowners should address at least three different aspects of home retrofitting. First, it will address the large environmental footprint imposed by the existing suburban housing stock. The environmental impact of current suburban homes is significant and negative, as argued by Blais (2011) and Rees and Roseland (1991). The DSS will show homeowners how to reduce their environmental footprint, what is applicable to their home and how they can accomplish this. It will advocate for structural changes rather than cosmetic solutions. Secondly, there is a lack of adequate housing types to meet the needs of shifting demographics in the suburbs as argued in the literature review. The DSS will show homeowners how they can retrofit their home to create more diverse housing types. Lastly, the tool will address the intersection of reducing environmental impact and creating new housing types. This intersection occurs when an addition is needed, possibly precipitated when a homeowner creates new units or when they retrofit to reduce their environmental impact. Additions should be built with sustainable and resilient materials and the DSS will help homeowners select these materials. An integrated DSS that address suburban resiliency would do well to address these three issues.

As shown in the flowchart in Figure 3.1, a DSS that did all of these things could be run as individual modules or executed in an integrated manner. Since each homeowner's preference and goals will differ from case to case, the DSS should be able to accommodate these distinct goals, within reason. It should allow each individual module of the DSS to stand on its own or work in conjunction with one or both of the other modules.

3.3. DSS COMPONENTS

To build a DSS that can help homeowners retrofit their suburban home, an understanding of the three aspects introduced above is needed. A literature review was undertaken to specifically address the three aspects of suburban retrofitting discussed in section 3.1, compiling relevant information to be built into the DSS.

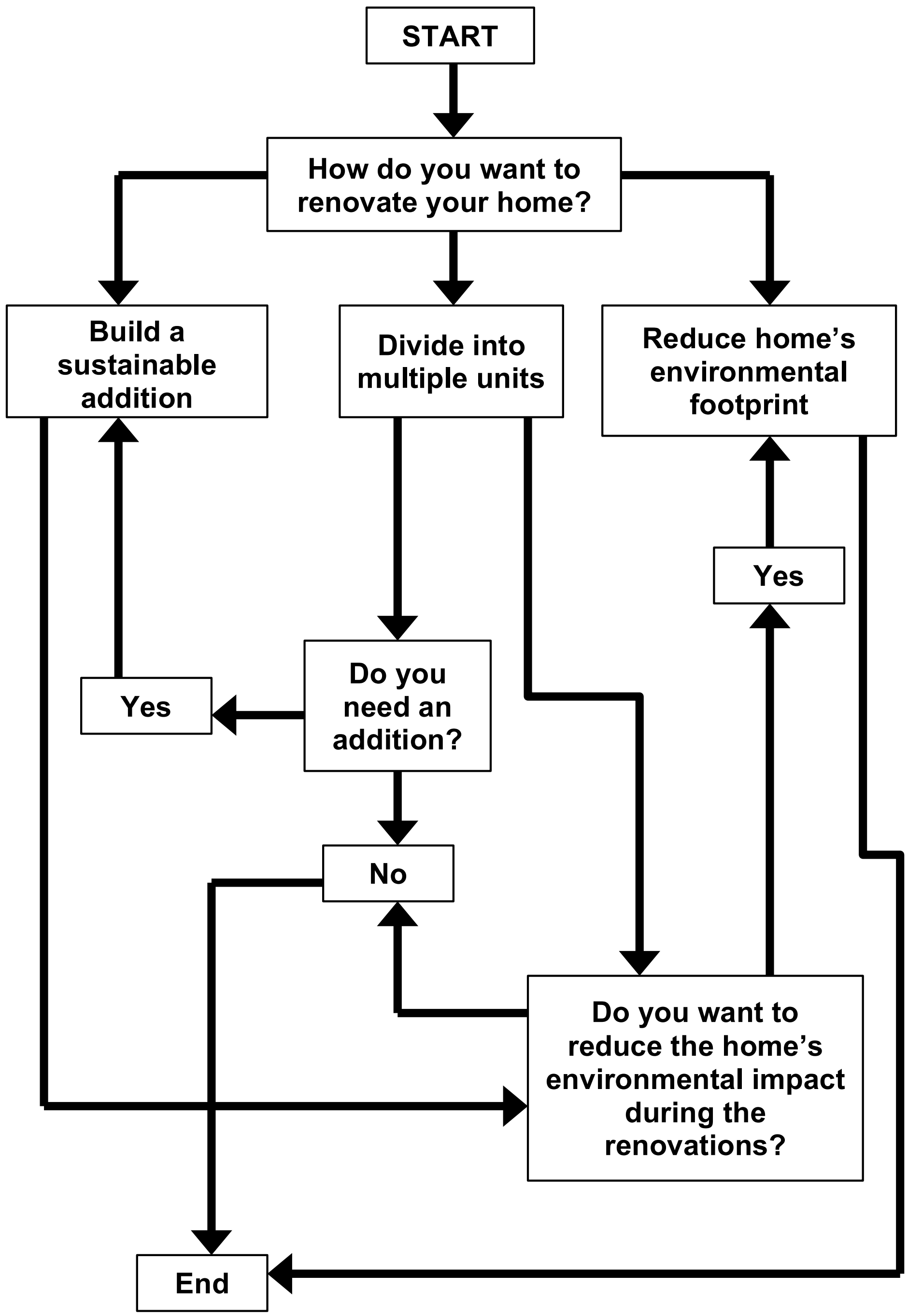


Figure 3.1: Flow Chart of the Conceptual DSS

To address dividing homes the review looked at home design, space management, and home adaptation. To address sustainable building materials, environmentally conscious building methods and materials were researched. Finally, to address the large environmental impact of the home, tactics for reducing this impact were researched. The review results are presented in the proceeding sections. Upon concluding this review and compiling important information and outlining a conceptual DSS, the development of a DSS into a working prototype is detailed in Chapter 4.

3.4. DIVIDING SUBURBAN HOMES

Brown and North (2010) and The National Trust for Historic Preservation (2011) both argue that from an environmental performance perspective, retrofitting and renovating homes is better than building new. Both Friedman (2002) and the CMHC (1999a) argue that retrofitting homes and making homes more adaptable to future change is necessary. Adaptation is when a home is altered from its original design to meet the needs of the occupants. Its one of the best ways to address the needs posed by changing lifestyles and demographics while keeping environmental impacts low. Adaptation can also address important issues such as income inequality and affordability issues (Friedman, 2002; CMHC, 1999a) and address the environmental impact of buildings (National Trust for Historic Building Preservation, 2011). The case for retrofitting suburban homes by dividing them into multiple units is further bolstered by the argument that modern society is demanding an ever-wider variety of housing types (Friedman, 2002).

CMHC (1999a) outlines the following reasons that adapting a home to new circumstances is better than moving: moving expenses can be larger than retrofitting costs, making staying in place a financially attractive option; income can be gained by creating an apartment in unneeded space; home offices or accommodation for live-in care can save on travel expenses; bringing people together in the same home means expenses can be shared, such as when grandparents babysit grandchildren; families, the elderly or other people who would otherwise have to move can stay in their own community and; sprawl can be reduced and resources used efficiently.

These reasons along with some of the issues raised in the literature review show that dividing large suburban homes into multi-family dwellings can meet many of these needs and challenges while providing added benefits. The division of homes is an adaptation measure taken to increase resilience of a suburban community. Since the housing stock already exists and many homes are large enough to accommodate multiple units (as will be shown in Section 4.1), the division of suburban homes has been selected as the adaptation measure of choice for creating new housing stock in this DSS.

A divided home is a smaller, more affordable home giving more people the chance to own their own living space. Thus suburbs on the brink of decline can use the pride of ownership to fight blight (Friedman & Pantelopoulos, 1996). Smaller homes are also cheaper to furnish because they impose strict limits on the accumulation of new "stuff" (Friedman & Pantelopoulos, 1996; Wilson & Boehland; 2005). Small sizes should not be seen as a hindrance to home sales since people are often willing to trade off home size for ownership (Friedman & Pantelopoulos, 1996). Dividing a home into two dwellings will cut operating expenses for the occupants of each new unit by roughly half or more and increase the density of the overall community. While not the only solution or necessarily the best solution in all cases, dividing homes into multifamily dwellings is a viable tool to use when retrofitting suburbs.

3.4.1. Creating Architectural Design Guidelines for the Division of Homes

The division of homes must be done properly, especially from an architectural point of view. Division requires changes to the layout of the home and should abide by sound design guidelines. Architectural design guidelines would ensure that the new units created use space effectively and provide a functional dwelling. A poorly designed home can have very negative consequences on the quality of life for the occupants (Brown & North, 2010).

Brown and North (2010) have created guidelines for what they call a "slow home". A slow home is simply a well designed home that is functional and has a small environmental footprint. Inspired by the slow food movement, Brown and North (2010) describe a slow home below:

> "a slow home is thoughtfully designed… is situated in a location that minimizes car use, is oriented properly to the sun, and incorporates environmental performance strategies. It responds to its climate, its site, and the real needs of the people who live in it. Finally a slow home facilitates not just the functional needs of daily life but the broader social and emotional dimensions of a home. When taken together, these features help make a slow home a more stable and profitable long-term investment for the homeowner than a fast house of equivalent size and cost"

This description of good residential design, or a "slow home", has been used as a reference point in this DSS for understanding how to divide homes into well designed units. When dividing suburban homes, site selection and home orientation will often be constrained because it deals with an existing home. Unfortunately, many suburban homes have not been sited well in terms of solar orientation and walkability (Brown & North, 2010). However, home division can improve the walkability of a community. As suburban population densities rise, walkable services become increasingly viable. Solar orientation will be harder to address, but there are some strategies that can help mitigate poor solar orientation. Some of these are addressed in the division of the home, while others are addressed when reducing the home's environmental impact.

The guiding principle of the slow home can be broken down as shown in Table 3.1. This table conveniently summarizes the guiding principles and vision of a slow home. When dividing a suburban home, the new units created should strive to be "slow homes". The Slow Home test has been included in Appendix A. It is a useful tool developed by Brown and North (2010) for quickly evaluating whether a home is a slow home and well designed. It would be a great way for DSS users to quickly evaluate their own home or a redesigned home.

Brown and North (2010) argue that good design should be considered first before using high-tech gadgets and machines to lessen a home's environmental impact. For example they argue that one should reduce driving by picking a location close to daily destinations before installing geothermal heating; the home should be of the right size for the family before installing energy and water-saving devices; solar orientation should be considered before using high-tech windows; and that low environmental-impact materials are wasted on a house that has been poorly designed and will need to be fixed in the near future.

Table 3.1: Guiding Principles of the "Slow Home" (Brown & North, 2010)

Simple to Live in and fits the way you actually live	**Light on the Environment and reduces your environmental footprint**
• Efficiently organized without wasted space • Rooms are effectively sized and proportioned to fit their purpose • Flexible long-term use • Good natural daylight and ventilation	• Located close to work, school, and amenities to reduce car use • Located in a walkable community • Correctly oriented to the sun and prevailing winds • Conserves land, water, and energy and makes a positive contribution to its community

The DSS must give homeowners sound design guidelines if they are going to divide their home. Brown and North (2010) also use pictorial examples of home floor plans to effectively demonstrate their own design points. This DSS should also have good examples of suburban homes that have been divided into multiple units so users can see how the guidelines are applied.

Appendix B shows the design guidelines that were developed after a review of home design literature and will be form the basis of the DSS. Since the examples used by Brown and North (2010) were so effective, this DSS will have examples of divided homes that use the design guidelines.

When dividing a home, there is a chance that an addition may be needed, especially on smaller homes. Additions can help homeowners meet the guidelines developed in section 3.4. The next section outlines the conceptual development of a system to help homeowners choose sustainable materials for an addition.

3.5. BUILDING MATERIALS FOR SUSTAINABLE ADDITIONS

Since additions can vary greatly in size they can often be viewed like new home construction. This is the approach taken in the development of this DSS. It assumes that the footprint of the home will be expanded and that the homeowner is concerned about their home's environmental impact but may not necessarily be completing work in other parts of the home to improve the home's environmental performance. It was also assumed that regardless of the construction material or method, construction practices would be up to the highest standards. This includes aspects such as meeting building code requirements, as well as ensuring an air-tight envelope and using appropriate windows and insulation.

An informal literature review of green building materials was undertaken to begin to decide what this DSS would address in terms of additions. This review revealed that there are many books and online resources for homeowners to consult to when picking non-structural materials such as flooring, wall coverings, and kitchen cabinets. Thus it seemed redundant for this DSS to address non-structural elements, especially since there are fewer legal limits for these aspects and homeowners can be creative and use various recycled or unconventional materials. When it comes to actual structural building materials there are few resources for homeowners to consult that advocate for any other type of construction than wood/stick-frame. There are certainly guides to picking sustainable wood but most guides seem to stick to conventional residential building methods and advocate for high insulation levels. This is certainly commendable, but there were other materials found in the review that should be considered due to their excellent environmental performance. However these methods were only for structural wall systems and their insulation. The other structural systems of the home such as the roof and foundation either have fewer opportunities for promoting alternative building materials or need further research and development and have not been addressed.

To select recommended building materials, an overview of structural residential building methods was completed. Building methods that were economically unviable, resulted in a poor indoor environment (temperature control, moisture control, etc), or not yet proven in application were not considered. Table 4.11, Table 4.12, and Table 4.13 were completed to help determine the best building materials. After completing this matrix, straw bale construction and earth-based building including adobe and rammed earth were selected.

While other methods such as super insulation using the conventional stick-frame construction method, insulated structural panels (ISPs), and insulated concrete forms were considered, they do not perform as well in many the categories considered. Many require more complex chemicals in the form of extruded foam panels, use more wood than the chosen methods, or cannot be sourced as locally. The beneficial aspects of straw bale construction and earth-based building are outlined below. The main drawback to these chosen methods has to do with either ill-informed preconceived notions about their suitability as building materials or a lack of widespread practitioners, skilled in these construction methods (Magwood et al, 2005). However, the preconceived notions can be changed through proven application and through the existing literature that supports these materials as safe, sustainable, and resilient. The lack of widespread use in the construction industry was not weighted heavily simply due to the fact that the building industry is notoriously conservative and wary of change. In many cases it takes the industry 3-15 years to adopt new building technologies or methods (Friedman, 2002) and the need for change as demonstrated in the suburban retrofitting literature review is too pressing to withhold advocating these methods.

From an aesthetic or architectural perspective, these methods are extremely versatile. They can be made to look quite unique with curved walls and interesting built-in features or they can be made to look quite conventional, complimenting the style of the existing home and neighbourhood (Bruce, 2000).

For the purposes here an addition was considered to be a continuous space of at least 23 square meters (250 square feet), or about the size of a new kitchen and living room. At this size, it starts to make sense to look at the building materials suggested here. For smaller additions, bump-outs or small extensions it makes sense to stick with conventional stick-frame construction for cost purposes. Susanka and Vassallo (2009) show a number of examples of how small and inexpensive changes such as bump-outs can greatly improve a space. For Susakna and Vassallo (2009), additions larger than 23 square meters start to really change the home and become more expensive. Recall that it was assumed that the homeowners would not necessarily be renovating the rest of the home for energy efficiency. This means that while the new addition can help the home's energy efficiency by being built properly, this is not its main goal. Thus any attempts to make the addition green will need to come from the building materials themselves. Each building method and material is outlined below to determine their applicability in various situations.

3.5.1. Straw Bale

Straw bale construction has been around for over a century and has proven a sustainable and resilient building material. It originated in Nebraska where a lack of lumber prompted the inventive use of straw for building pioneer homesteads (Magwood et al., 2005). Note that it is straw, which has low moisture content and is a byproduct of cereal grain production that is used, not hay. Straw bale homes are constructed by laying square straw bales down akin to bricks and plastering both the inside and outside with a breathable plaster (Vardy & MacDougall, 2006: Magwood et al, 2005). Straw has the benefits of often being produced locally, it is cheap, readily renewable, has an excellent insulation value, and requires less wood for construction than a stick-framed home (Magwood et al, 2005). An example of a straw bale home that is representative of the size of an addition is shown in Figure 3.2.

Figure 3.2: A straw bale studio (Straw Bale Innovations, LLC, 2011)

Straw is a low-value by-product of agriculture and when sourced locally can be bought and shipped at a very reasonable cost. Any type of straw will do. The amount of straw produced in North America is so great that there is enough to meet all residential building requirements each year (Magwood et al., 2005). Not only is straw a proven structural building material, it is also an excellent insulator and if designed properly a straw bale home can reduce or even eliminate the need for a furnace or air-conditioner. In tests it has been rated at of R-30 and this is the generally accepted value in the industry (Magwood et al., 2005). However, the thermal mass of the straw-plaster system, allows the wall to effectively behave like an R-40 or R-50 insulated wall (Magwood et al., 2005). These insulation levels make it a great choice for both hot and cold climates.

There are often concerns about moisture and rot, mice, and fire hazards with straw bale construction. These are all reasonable but unfounded concerns.

Moisture and rot can be a problem if the additions are designed improperly, but this is no different than any other home that has been improperly designed (Magwood et al., 2005). In rainy climates the homes must be designed with large overhangs to prevent water from soaking the walls and the bales are set on a raised foundation to keep them away from the moisture in the ground that can wick up through the plaster and bales. When designed to accepted standards, straw bale construction will have no moisture or rot problems and will actually help moderate humidity in the home (Magwood et al., 2005; Carfrae, 2011). A recent study of straw bale construction showed that a properly designed and constructed straw bale home could handle the moisture in the wet and rainy temperate maritime climate of England (Carfrae, 2011). Any climate that is more arid than this is an acceptable place to build with straw bale from a climate perspective. However, more research is needed to test straw's performance in hot humid climates such as those in the American southwest (Carfrae, 2011).

Straw bale homes provide unsuitable habitat for mice and rodents. Straw has low nutritional value and the tightly packed bales do not allow for mice to burrow easily. Mice would rather live in the hollow walls and insulation batt of a conventional home (Magwood at al. 2005).

Straw bales have been shown in standardized fire tests to exceed the fire-safety requirements for residential homes (Omega Point Laboratories, 2000; Development Centre for Appropriate Technologies, 1993). Their density and the fact that they are covered in a non-flammable plaster make them extremely fire resistant, more so than conventional wood-frame construction (Magwood, et al., 2005).

There are two main types of straw bale construction: non-load-bearing and load bearing. The non-load-bearing method uses wood frame (conventional stick-frame, timber frame, etc.) as the structural wall system and the bales are used only as insulation and infill (Magwood, et al., 2005). This method requires the same amount of wood as a conventional wood-frame home. The load-bearing straw bale home on the other hand uses the plaster and bales as the main structural wall system (Magwood et al., 2005). Vardy and MacDougall (2006) have demonstrated that this type of construction greatly exceeds the code requirements for load bearing walls and many existing straw bale homes use this type of construction (Ontario Straw Bale Building Coalition, 2012). Due to their low wood content, the load-bearing style is the one recommended in this DSS.

In the case of additions, straw bale should be chosen where straw is readily available and the climate is not hot and humid. The recent study by Carfrae (2011) shows that the American Southeast is the only place of concern for straw bale construction because there is currently insufficient research on the performance of straw bale construction in this climate.

Wheat production is one of the most significant sources of straw with other cereal grains making up a more modest amount (Magwood et al., 2005). In Canada, wheat is the most important economic crop and is grown commercially in all provinces except Newfoundland and Labrador (Natural Resources Canada, 1996). Wheat production can be found near virtually all large population centers and many smaller ones as well (Natural Resources Canada, 1996). Wheat is grown commercially in all US states and is a very important agricultural crop (Pillsbury & Florin, 1996). There may be a less local availability in Maine, Southern Nevada, and northern New Mexico and Arizona (Pillsbury & Florin, 1996).

3.5.2. Earth-Based Construction

The earth-based construction methods recommended for use in the DSS are adobe and rammed earth. These are ancient building methods and buildings made of both building materials that are hundreds of years old still standing today (Bruce, 2000). Both adobe (King, 2000) and rammed earth (Minke, 2000) are very strong building materials easily meeting the structural requirements of building codes. They have excellent thermal mass and in locations where the average temperature is within the range of 18-27^{o}C, no insulation is needed

(Bruce, 2000). As with straw bale or any residential construction method for that matter, protection from moisture is important. Simple design features like sufficient roof overhangs can easily handle these issues (Bruce, 2000).

3.5.3. Adobe

Adobe is a method of building that uses adobe bricks, called adobes. These bricks differ from conventional bricks in that they are made of soil, cured by baking them in the sun in casting forms. As long as the right soil is present and the climate is favourable for baking the bricks (sunny, warm, and dry), the bricks can be made locally, even on-site from soil excavated from the foundation. When constructing the home, the bricks are stacked in the same manner as normal bricks, then plastered on the outside and inside similar to stucco. This gives them great versatility for creative designs; bricks can be made in various sizes and can be easily formed into curved or straight walls. A plastered adobe home that has not been covered with any siding looks very similar to a plastered straw bale home as shown in Figure 3.2. Adobe bricks can be bought in some locations or made by hand if there is a knowledgeable craftsman. They are labour-intensive to make since they are crafted by hand and cured in the sun rather than mass-produced in a mechanized industrial process (Moquin, 2000).

The environmental impact of adobe production is miniscule compared to conventional bricks. Brick for brick, it takes 1% of the energy to make an adobe brick as it does to make an equivalent fired brick or Portland cement brick (Moquin, 2000). Further increasing their environmental performance, locally sourced adobe can replace more than 50% of the wood required to build the same conventionally stick-framed house (Moquin, 2000).

As a form of earth-based building, adobe is one of the oldest methods of building on the earth. Like rammed earth, there are many adobe buildings that are centuries old. They are extremely strong buildings and with stabilizers can reach strengths ranging from 6.9 MPa to 41.4 MPa, easily meeting building codes

(King, 2000). Since they are made of soil, adobe buildings are inherently fire and rodent-proof (Moquin, 2000).

Adobe has excellent thermal mass characteristics and can help moderate temperature in places where it gets very hot during the middle of the day (Moquin, 2000). Walls of 20 to 30 cm seem to give the optimal thermal mass characteristics (Moquin, 2000). In climates where the average daily temperature is in the comfort zone ($18^{o}C$ to $25^{o}C$) no insulation or substantial heating or cooling system will be needed as the thermal mass will moderate temperature (Moquin, 2000). However, in cold or hot climates, insulation will be needed since adobe buildings have an insulation value of only about R-20. This insulation is usually in the form of rigid extruded foam on the outside of the building. This leaves the thermal mass exposed on the inside, letting the indoor environment benefit from the thermal mass' temperature moderating effects (Moquin, 2000).

Like any other building, adobe should be protected from moisture and should not be built where flooding is a risk (Moquin, 2000). Raised foundations can help prevent the adobe from soaking in moisture from the ground via capillary action and in wet areas a large overhang and special additives can be used to protect the home from moisture (Moquin, 2000). In humid climates, adobe can actually help control humidity in the home by soaking in the moisture to its dry bricks. Adobe has been shown to increase in strength with increasing levels of humidity with peak strength being reached at 60% RH (Moquin, 2000; Minke, 2006). However, care must be taken to ensure excess moisture is not present in the walls during freeze-thaw cycles or damage can result (King, 2000).

3.5.4. Rammed Earth

Rammed earth construction is an earth-based construction technique like adobe. It has been used for centuries in many different cultures across the world and has proven itself a durable and reliable building material in all climates. Soil is poured into forms similar to the forms used for building concrete walls and then tamped down (Minke, 2006). This is done in layers, slowly building the wall up inches at a time. The wall needs no plaster on the outside and the walls often show the different coloured layers of the soil in an appealing way. Figure 3.3 shows a rammed earth home with the earth exposed on the bottom and covered with wood siding on the top. The soil used must be of the right composition and contain virtually no organic matter (Minke, 2006). The rammed earth can be stabilized by adding small amounts of cement and when finished can be stronger than concrete walls of the same size (Minke, 2006). This building technique is labour intensive but the building material can be sourced from local soil and when demolished, the walls simply become earth again (Minke, 2006).

Since rammed earth is made of soil, it has very similar characteristics to adobe. Thermally, it can moderate temperature with its thermal mass and can perform in hot and cold climates with a layer of rigid extruded foam sandwiched in the centre of the wall. Like adobe it must be protected from moisture but can also moderate humidity (Minke, 2006). Since adobe and rammed earth are very similar, choice of which method to use is largely based on personal preference, access to knowledge on the building techniques, and whether the climate is favourable for baking adobe bricks. From a structural and thermal point of view they are almost the same.

In developing both the dividing homes and sustainable additions sections, there is an obvious flow to the final section that looks at how homeowners can reduce the environmental impact of their homes. When a homeowner chooses to divide their home or put on a sustainable addition it is good opportunity to also recue the impact of their homes. At the time of a major renovation these methods can easily be incorporated. The next section conceptually develops a way to systematically evaluate and design feature that reduces the environmental impact of the home

Figure 3.3: A rammed earth home (Schooley, 2008)

3.6. REDUCING THE ENVIRONMENTAL IMPACT OF SUBURBAN HOMES

The goal of this section of the DSS is to help homeowners identify what would work best for them in terms of reducing their home's environmental impact. There are many well-developed methods and ideas for retrofitting a suburban home to reduce its environmental impact. However many have different benefits, different impacts, or are only applicable in certain circumstances while others are simply cosmetic with little impact. This variability makes it difficult for homeowners to make informed choices when they want to reduce the impact of their home. Questions arise such as: should I look at energy use or water conservation? What are the different ways to reduce impact? Which ones should I do? How much will it cost and will it pay itself back? While there are many books ranging from highly technical to basic and simple, there seems to be no comprehensive tool to help homeowners determine which options are best for them. This part of the DSS aims to address this shortcoming.

A literature review was undertaken to investigate ways to reduce the environmental impact of a suburban home. The tactics that seemed most relevant to suburban homeowners were selected. They were then divided into three categories: water use (potable), energy use, and stormwater management (including yard/property management). The following sections provide an explanation of each section and how it relates to the home's environmental impact. These categories were further broken down into individual tactics. For details the individual tactics of each section see the primers in Appendix E.

3.6.1. Water Use (Indoor)

Considering that significant water shortages across the world and in Canada are occurring or imminent (Schindler & Donahue, 2006), that Canadians use the second most amount of water in the world per capita, and that residential use accounts for more than half of all municipal water use (Environment Canada, 2011), water conservation and reuse strategies in the suburbs must be addressed. Another important argument for water conservation and reuse is that municipal water infrastructure across Canada and the US is aging and in need of billions in investment (ASCE, 2009). This has led to a financial strain on municipalities and subsequently increases in the costs of municipal water and sewer charges (Environment Canada, 2011; AECOM, 2009). The treatment and conveyance technologies used by municipalities to get water to the home also require large amounts of energy (Maas, 2010). These infrastructural factors coupled with water shortages driven by population increases and climate change across the world, including Canada and the United States, means that better water management practices translate into economic savings as well as water security (Schindler & Donahue, 2006) and thus community resilience.

This module looks at reducing water use, reusing water on-site, and the treatment of water on-site for indoor use. With the exception of low-flow fixtures, water reuse and treatment are large projects requiring proper planning and design and are initially quite expensive (CGBC, 2011). To maximize their effectiveness, a water management plan for the home or homes should be designed with professional help (CGBC, 2011). This will allow the integration of multiple water reduction and treatment methods to work together in a system providing the largest positive impact and best return on investment.

These projects are often best implemented when a large renovation of the home is taking place, as they require opening up, rerouting and installing plumbing and treatment systems throughout the home (CGBC, 2011). While these projects have large initial capital costs, their operational costs are quite low. As energy and municipal water prices increase, these technologies will begin to pay themselves back faster, making them an attractive alternative to the traditional centralized municipal system (CGBC, 2011; Environment Canada, 2011). Despite their economic and environmental benefits, these systems are not widely used and many municipalities have bylaws against certain technologies or no bylaws at all (CGBC, 2011).

The tactics found to be most applicable and having the highest impact were included in the DSS. They are: low-flow fixtures, grey water reuse, composting toilets, and wastewater treatment. The primers in Appendix E contain detailed information on each tactic.

The DSS does not address the behavioural changes required to reduce water use nor does it recommend any sort of water management plan, but both will likely be needed.

3.6.2. Stormwater Management

According to the Ontario Ministry of the Environment's *Stormwater Management Planning and Design Manual 2003,* the ultimate goal of stormwater best management practices is to maintain the predevelopment natural hydrologic cycle of a given area. This does not often happen with traditional stormwater management practices in the suburbs. In natural conditions, rainwater lands on a vegetative surface and then takes one of several avenues within the hydrologic cycle: evapotranspiration to the atmosphere, surface flow to a receiving body of water (creek/stream, river, lake), deep infiltration (baseflow) to an aquifer, or shallow infiltration (interflow) to a receiving body of water (Ontario MOE, 2003). This cycle can be altered significantly due to urbanization and the increase in impermeable surfaces to the great detriment of the surrounding ecosystems. In general, surface flow increases dramatically with urbanization and can overwhelm surface water bodies with excessive and damaging flows while evapotranspiration and infiltration decrease. The impacts of urbanization and the increase of impermeable surfaces on the hydrologic cycle have been extensively documented and include, but are not limited to: pollution, erosion, nutrient loading, and reduced baseflow (Prince George’s County, 2007; Maryland Department of the Environment, 2009).

The other goals of stormwater best management practices include (Ontario MOE, 2003):

> “preserving groundwater and baseflow characteristics; preventing undesirable and costly geomorphic change in the watercourse; preventing any increase in flood risk potential; protecting water quality; and ultimately maintaining an appropriate diversity of aquatic life and opportunities for human uses.”

In urban settings it has been identified that lot-level controls for managing stormwater are the optimal choice for maintaining the local hydrologic cycle (Ontario MOE, 2003). Lot level controls are features that are contained on a single lot (or a relatively small area) that allow stormwater to flow, as it naturally would have before development. This makes lot level controls very applicable to, and accessible for, individual suburban homeowners.

It is important to address the fact that, virtually regardless of soil type, urban lawns have the lowest level of stormwater infiltration in comparison with other types of vegetative cover (Ontario MOE, 2003). Thus suburban homes not only often have large impermeable surfaces in the form of roofs, driveways, and patios, their lawns also often have poor infiltration characteristics in comparison to predevelopment conditions. Fortunately there has been an increased interest in lot-level controls in the recent past and there is a growing body of knowledge to help homeowners implement effective lot-level controls (Davis et al, 2009; Prince George's County, 2007; Maryland Department of the Environment, 2009).

There is not only an ecological impact for improper stormwater management but a financial one as well. There are currently approximately 15 municipalities in Canada that have investigated or implemented a stormwater rate, a fee that landowners pay to fund storm sewer infrastructure. This infrastructure is currently in poor disrepair and in need of investment in many municipalities across North America (AECOM, 2011). The basis of the stormwater rate is that landowners should be charged for stormwater runoff based on how much their property produces (AECOM, 2011). The conventional method for funding stormwater infrastructure uses funds collected from the general tax base and does not consider the amount of runoff each landowner contributes to the system. The rate system is seen as the most equitable system and a method for sustainably funding stormwater infrastructure without having to cut spending to other services that draw on funds from the general tax base (AECOM, 2011). Under this system there is the possibility that landowners would be offered credits for implementing lot level controls that divert water away from storm sewers. With rates ranging from $4/month to $10/month for the majority of residential landowners, there is a significant opportunity to realize short paybacks with simple lot level controls (AECOM. 2009).

This portion of the DSS presents the most relevant lot-level controls for stormwater management in residential use. The lot level controls proposed here are able to handle the quality and quantity of water that would drain from a suburban property. It is assumed runoff water contains few sediments or chemical pollution. If there is a risk of pollution as car oils, coolants, or cleaners entering the device this can pose pollution issues for the surrounding watershed or could cause clogging of the lot-level device.

Appendix E documents the lot-level controls proposed for residential use in this DSS. They are: rainwater harvesting, soakaway pits, yard ponding, rain gardens (bioretention), and permeable paving. Also included in this section is the naturalization of the property including a practice called xeriscaping that seeks to reduce the need for irrigation. While not a lot-level control *per se*, natrualization does have water quality and use implications and is thus included in this section.

3.6.3. Home Energy Use

Suburban homes consume large amounts of energy and while there are behavioural changes that can be made to reduce energy use (Suzuki & Boyd, 2008), a significant amount of the home's energy use is predetermined based on home design (Brown & North, 2010). In most cases the suburban home is standard across North America in terms of building methods, materials, layout, and heating and cooling systems. This neglects the fact that the climate varies widely and different types of architecture are appropriate for each environment, something called vernacular architecture (Magwood et al., 2005). The energy section looks at how homeowners can retrofit their home to reduce their reliance on imported energy in the form of electricity or fossil fuels and make them more appropriate for the local climate.

Not investigated here are the gains that can be made from replacing appliances and light fixtures with more efficient models. It has been assumed that homeowners have already taken these easy steps. Nor does it address how changes in lifestyle, such as choosing to sleep in the basement to take advantage of its coolness in the summer can reduce energy consumption. There are many books and resources that look at how home appliances and lifestyle changes can reduce energy consumption. It would be redundant and of little value to include this information.

This section specifically looks at strategies that can be implemented on existing homes to increase resiliency. As recommended by Brown and North (2010) these strategies help eliminate the need for high efficiency HVAC systems or appliances. They address the design of the home first and foremost.

After reviewing the literature on design strategies to reduce the home energy use, 6 tactics were chosen. They are: passive solar heating, natural ventilation for cooling, natural lighting, solar water heating, solar PV, insulation, and energy efficient landscaping. Appendix E explains each tactic in detail. Not investigated here are more mechanical strategies for heating and cooling such as geothermal heat-pumps, radiant floor heating, high efficiency air-conditioners and furnaces, and high-efficiency wood-pellet stoves. Currently there is much hype around these measures and some are even subsidized by certain governments via rebates and tax incentives (Ontario Ministry of Energy, 2012). However, they all rely heavily on fossil fuel or electricity (often derived from fossil fuels), thus decreasing their overall resiliency in the long term. When designing for a residence, these types of strategies should be eliminated if possible and used minimally when required (Brown & North, 2010).

3.7. MOVING TO DETAILED DSS DESIGN

This completes the review of literature and conceptual design of the DSS. This conceptual development of the DSS provides two valuable tools moving forward. First is a flow chart for how the DSS will work, as shown in Figure 3.1. This will guide the detailed development of the DSS. The second is a solid understanding of the design aspects of each component of the DSS. The knowledge required for dividing suburban homes, selecting materials for additions, and retrofitting suburban homes for energy efficiency has been amassed but not combined. The most important tactics and design approaches have been retained. Chapter 4, DSS Detailed Development, will link this knowledge together by creating modules for each section as well as integrating the modules together for use as a single DSS.

4. DSS DETAILED DEVELOPMENT

Chapter 3 explained the conceptual development for the DSS. Specifically it laid out a general flow chart depicting how the DSS would work and developed and divided the research into the three main components of the DSS. The components will be developed in this chapter into three modules: the dividing suburban homes module, the sustainable additions module, and the reduction of environmental impact module. First, each module will be developed on its own since each must be able to perform as a stand-alone tool, a requirement established in Chapter 3. After individual development, the modules will be appropriately linked together and integrated.

4.1. DIVIDING SUBURBAN HOMES MODULE DEVELOPMENT

Recall from Chapter 3, that a literature review of home design was completed and a list of design guidelines that divided homes should strive to meet was developed. Also noted from the work of Brown and North (2010) was the effectiveness of visual examples for explaining good and bad home design. From this list of guidelines and some visual examples this module can be built. The guidelines are the written documentation, while the examples are the application of this documentation. Together these can be combined to make an effective tool.

The guidelines are fairly straightforward and amounted to 54 guidelines in total. Several pertain specifically to dividing homes, another few pertain to privacy which is important when people are living in close quarters, and the rest are general to good home design. Appendix B shows the full list, broken down by areas in the home. This list of guidelines is a compilation of multiple sources and while not comprehensive, represents the basic rules many home designers follow. The guidelines are broken down by area in the home, such as the living room, entryway, kitchen, etc. This was done to bring some sort of order and organization to the long list of design guidelines. Each area has a brief description where necessary to explain the important aspects of that area of the home.

After forming this list, a review of suburban home designs currently being marketed by builders in the Greater Toronto Area (GTA) was completed to informally investigate design trends. With the guidelines in hand, quick and informal evaluations of these homes were completed. These evaluations were made to see if there were certain commonalities between suburban homes that could be exploited in a systematic way to make the application of the guidelines easier. The possibility of the tool containing a software package where home designs were loaded into a computer program and the software would produce divided plans was also contemplated. It was found that there was enough variability in the home designs that a systematic method for applying the guidelines would not be feasible nor make sense. Each design would have to be considered on a case-by-case basis making a software package difficult to create.

There were however some common features of note: double garages built into the front of the home; kitchens generally at the rear of the home; two eating areas; two living areas; 2-5 full bathrooms as well a powder room; large foyers; and master suites usually at the rear of the home, generally the equivalent size of a kitchen, living area and small eating area. These features did prove exploitable and are explained in the following examples.

After this review of designs, 10 designs were selected for possible division into multiple units as they seemed to have features that would be conducive to meeting the guidelines. After testing the guidelines out on these designs using hand sketches, it became apparent that there were some significant barriers to dividing certain designs. From this experience came the idea to include in the module an example of a home that had features that made it feasible to divide. From these 10 plans, three were selected to apply the division guidelines since they seemed conducive to division and each produced uniquely different unit types after the division. After this review it was also determined that a “large” suburban home, or one that seems large enough to lend itself to a division is about 2500 square feet or larger, as advertised by the home builder. This size excludes the basement that is often unfinished. This definition does not exclude homes smaller than 2500 square feet from division, but for the purposes here large means 2500 square feet or larger.

The three redesigns are shown in the following category and the layout of each example is very similar to what has been included in the actual DSS. The redesigns were completed in AutoCAD. Their presentation are similar to floor plans found on a home developer's website; general dimensions, labels, and not to scale. In order to make the examples effective and information-rich, each includes several important features. The first is an introductory discussion to the home plan that includes the basic outcomes of the division as well as costs. The second is a clear diagram of the before and after layout of the divided or converted home. This layout was completed according to the developed guidelines. The third is a breakdown of the costs of the division. The major costs of the division were estimated to get a feel for an approximation of the cost of the conversion. Appendix C has a breakdown of unit costs for construction and estimate sources. The fourth are the redesigned plans, with clear indications of where important guidelines were used. Finally, the impact of government grants and/or income from rent are explored to how these divisions can create income and pay themselves back.

4.1.1. Inlaw-Suite Conversion Example

The in-law suite conversion takes a 2923 square foot, 5 bedroom, 3 ½ bathroom home and converts it to a 2 bedroom, 1 bathroom *in-law suite* and a 3 bedroom, 2 ½ bathroom single family home or *primary unit.* This is shown in Figure 4.1 below. This home was adapted from Sundial Homes Limited's (2006) design for a home they build in the Greater Toronto Area. This division addresses housing needs for North America's aging population by creating an in-law suite that has accessible features. It is on the ground floor and has a kitchen and bathroom large enough for a wheelchair or walker.

This type of conversion could suit a family who wants to bring aging parents closer. There is also the possibility of simply using it as a rental unit for income purposes. The estimated cost of this conversion is $55,300. Table 4.1 shows a breakdown of the costs of construction. This conversion was the most expensive of the three examples, largely because a new bathroom needed to be constructed. In the other conversion examples, existing bathrooms were used and no new bathrooms needed to be constructed. However there are several opportunities to lower this cost or recoup costs over a very short period. Table 4.3 shows some of these scenarios. Using rental income and financial incentive programs, costs from this conversion can be recouped in an estimated 3-5 years.

Some of the key design features of this conversion are explained in Table 4.2 and Figure 4.2. In addition to specific design features there are some general design features to note. The first point is that there are no complex geometries in the home. Walls meet at 90^o and there are no oversized features that require special accommodation in the conversion. Both units have been separated into private and public areas. The in-law suite has a wall that creates some privacy between the bedrooms and bathroom and the rest of the home. While this wall could be opened up, it would reduce privacy. In the primary unit, the bedrooms have been placed in the rear of the home while the kitchen, living, and dining room have been placed together at the front. Unfortunately connections to the outdoors from the living space in the primary unit are only a few windows. While the primary unit may look modest in size, it in fact is quite large since it has access to the basement. This opens up a number of possibilities for future basement uses.

Overall this conversion shows how some of the constraints of working within the existing footprint affect design. Many of the design guidelines have been met, while others have not. This shows how tradeoffs will have to be made in suburban conversions unless significant structural changes and increased costs incurred.

Figure 4.1: Top - Before; Bottom - After. Blue - In-law suite; Red - Primary unit

Table 4.1: Construction Cost Estimate for In-Law Suite

Construction Work	Dwelling Unit	Work Description	Quantity	Unit of Measure	Cost ($) CAD
Rough/General Carpentry					
Wall Demo	Main Unit - Upstairs	Open up front bedrooms and bath	424	sqft	$1,100
	In-law Suite	Remove laundry	110	sqft	$300
Wall Construction	In-law Suite	Create bedroom and bathroom	600	sqft	$5,200
Door Removal	Main Unit - Upstairs	Remove old front bedroom doors	6	each	$100
	In-law Suite	Remove laundry room doors	3	each	$100
Door Construction	In-law Suite	Bedrooms and Bath - Installation only	4	each	$100
Electrical	Whole Project	Everything	1	Flatrate	$10,000
			Rough Carpentry Subtotal		**$16,900**
Finishing Carpentry					
Flooring	In-law Suite	Carpet, New bedroom and hallway	170	sqft	$1,000
	In-law Suite	Ceramic, New bathroom	54	sqft	$300
	Main Unit - Upstairs	Hardwood, living room	284	sqft	$900
	Main Unit - Upstairs	Ceramic, Kitchen and Dining room	213	sqft	$1,200
Trim	Main Unit - Upstairs	Trim for new walls	22	sqft	$100
	In-law Suite	Trim for new walls	114	sqft	$400
Kitchen			**Finishing Carpentry Subtotal**		**$3,900**
Install Kitchen	Upstairs Unit	Cabinets, counter, installation	1	each	$12,000
Range	Upstairs Unit		1	each	$1,000
Range Hood	Upstairs Unit		1	each	$300
Fridge	Upstairs Unit		1	each	$1,000
Dishwasher	Upstairs Unit		1	each	$500
Microwave	Upstairs Unit		1	each	$300
Dishwasher and Sink hook-ups	Upstairs Unit		2	each	$1,200
				Kitchen Subtotal	**$16,300**
Bathroom					
New 3pc Bathroom	In-Law Suite		1	each	$9,000
				Bathroom Subtotal	**$9,000**
				Construction Subtotal	**$46,100**
Correction Factor	Cost Overruns and Underestimation			1.2	$55,300
				PROJECT TOTAL	**$55,300**

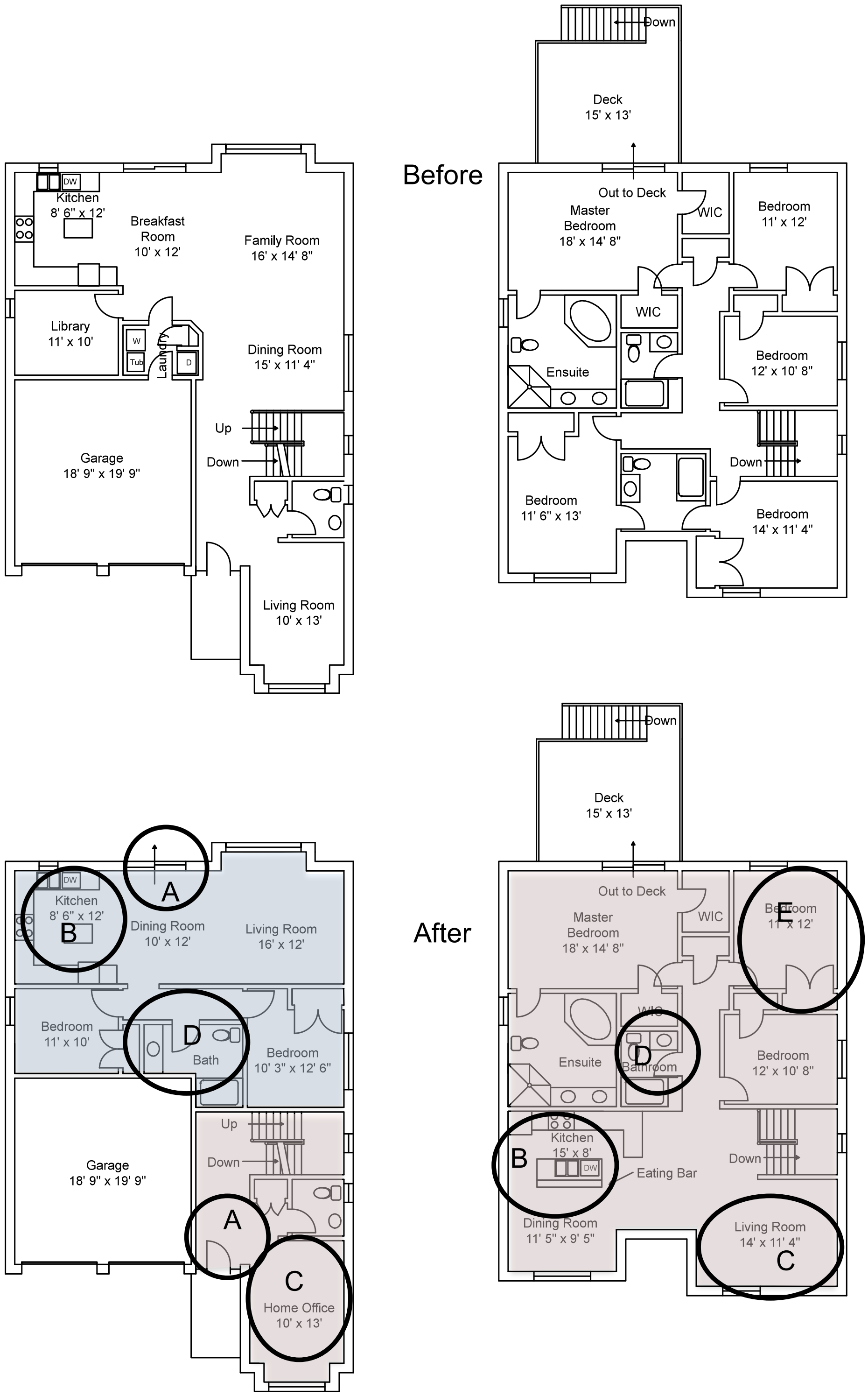


Figure 4.2: Key design features of the conversion

Table 4.2: Key design features of the converted units explained

Location	Corresponding Design Guideline	Explanation
A	22, 23, 24, 25	The entry has its own space, is large enough for a few people to converse and has storage nearby for coats and shoes. Notice the entry for the in-law suite is not as well placed due to space constraints. A creative design could possibly fix this.
B	26, 27, 30	Both kitchens look out over the living space. The primary unit has a well-designed work triangle and uses and island to hide kitchen messes.
C	33	There are two living spaces in the primary unit. The living room is one, while the home office could be used as a den or the basement could be finished to into a family room.
D	44	Bathrooms are private but accessible. Most use traditional layouts and the in-law suite bath has been sized for a wheel chair or walker.
E	45, 46, 47	All bedrooms are appropriately sized and have natural light and functioning windows. Most have closets that are inset into the wall and do not protrude into the room

Table 4.3: In-law suite conversion income scenarios

Income Source	Description	Amount		Final Project Cost	Simple Payback (Years)
		Grant	Rent*		
None	Apartment constructed for family member, no rent collected	N/A	N/A	$55,300	N/A
Apartment rental	Rent collected from tenants	N/A	$885	$55,300	5.2
RRAP Secondary/Garden Suite**	Grant from CMHC for construction cost and monthly rental	$24,000	$885	$31,300	2.9

*Average apartment rental amount from CMHC (2011). This rental amount is the average rental rate for the Hamilton CMA
**RRAP grant from (CMHC, 2012

4.1.2. Two Family Conversion Example

The two family conversion takes a 4 bedroom, 3 ½ bathroom, 2,808 square foot home and converts it into two 3 bedroom, 1 ½ bathroom dwellings. Both units are large enough for families with children. The original home plan comes from Reardon-Tagore (1999) and the conversion is estimated to cost $49,700, as shown in Table 4.4. There are several scenarios explored for recouping these costs that are shown in Table 4.6, with payback periods of 2.5 to 3 years. This conversion is a practical example of how a large home can using existing features and remove redundant features to accommodate two families.

The key to this successful conversion was finding extra living space in two very important areas: the basement and the attic. The *downstairs unit*, shown in blue in Figure 4.3, takes advantage of the basement for additional space. Although not shown in the plan, many suburban basements have common features and uses. They generally house the utilities such as the water heater, furnace, and electrical panel. They may also contain the laundry facilities, although in this case the laundry is on the main floor. Basements in new suburban homes usually have the plumbing 'roughed-in' for a full 3-piece bathroom and have space for a family room with space left over. For this conversion it has been assumed that a family lived in the home long enough to construct a family room and have a full bathroom in the basement prior to the conversion. It is also assumed that the family room and bathroom only take up half the basement while the other half was left unfinished. In this conversion the remaining unfinished basement space has been converted into two bedrooms. A simple conversion of the main floor living room to a bedroom completes the construction of the downstairs unit. When complete, the downstairs unit has a main floor living room, dining room, bedroom, den or office, kitchen and powder room and the basement contains the family room, primary bathroom, and two bedrooms. There are certainly other possible configurations and designs are not limited to what is shown here. Since the state of the basement is based on a likely scenario but depending on the actual state, more or less work may be needed. Specific design features of the downstairs unit are explained in Figure 4.4 and Table 4.5.

The upstairs unit, shown in red in Figure 4.3, takes advantage of the attic in the same way the downstairs unit took advantage of the basement. The conversion of homes into multiple units often uses floors to divide; the first floor is a unit, the second floor is a unit, and so on. It is often difficult to find space on the second floor of a suburban home to meet the spatial needs of a family with children. In this case the attic provides the extra space needed without the need for an expensive addition. Notice that the upstairs unit is separated into private and public space, keeping the bedrooms separate from the living space. In suburban homes, the master suite is often very large containing a walk-in closest(s) and a large master bathroom. This space is often large enough to create a living room, dining room, and kitchen as shown in this example. In this conversion the new kitchen has been placed where the old master bathroom was. This allows the new kitchen to use existing plumbing that had been used for the bathroom. This is an important design strategy: place new kitchens, bathrooms, or any rooms that need plumbing where plumbing already exists. It is very expensive to re-route plumbing through a finished home and should be avoided if possible. Specific design features of this unit are explained in Figure 4.4 and Table 4.5.

Due to the original placement of the laundry room, it ends up in a shared space after the conversion. However, it would be feasible for both units to have their own washer and dryer, but at a higher cost. The downstairs unit could have the laundry facilities located in the basement while the upstairs unit could locate a stacked washer dryer in the full bathroom or in the storage room.

Overall, this conversion shows how to use attics and basements to meet most of the design guidelines and how a large suburban home can be converted into two units that have an appropriate amount of space for two families with children. It also shows that there are many possibilities for redesigning and dividing homes depending on the wants and needs of the residents.

Figure 4.3: Top – Before; Bottom – After; Blue – Main floor unit; Red – Upstairs unit

Table 4.4: Construction Cost Estimation for Two Family Conversion

Construction Work	Dwelling Unit	Work Description	Quantity	Unit of Measure	Cost ($) CAD
Rough/General Carpentry					
Wall Demo	Upstairs Unit	Open master suite	268	sqft	$700
Wall Construction	Upstairs Unit	Close off Bathroom	40	sqft	$300
	Upstairs Unit	Create unit entrance	28	sqft	$200
	Dwnstrs Unit - Main Flr	Main floor bedroom	204	sqft	$1,800
	Dwnstrs Unit - Main Flr	Entrance to Unit	28	sqft	$200
	Dwnstrs Unit - Bsmnt	Bedrooms	368	sqft	$3,100
Door Removal	Upstairs Unit	Old Master Suite	4	each	$100
Door Construction	Upstairs Unit	Door to powder room	1	each	$200
	Upstairs Unit	Fire Door	1	each	$300
	Upstairs Unit	Sliding Door	1	each	$1,800
	Dwnstrs Unit - Main Flr	Fire Door	1	each	$300
	Dwnstrs Unit - Main Flr	Main floor bedroom	2	each	$400
	Dwnstrs Unit - Bsmnt	Install Bedroom Doors (install only)	2	each	$100
	Dwnstrs Unit - Bsmnt	Install New Bedroom Doors	2	each	$400
Deck	Upstairs Unit	Outdoor Space	180	sqft	$2,700
Electrical	Whole Project	Everything	1	Flatrate	$10,000
			Rough/General Carpentry Subtotal		**$22,600**
Finishing Carpentry					
Flooring	Upstairs Unit	Ceramic, Kitchen	108	sqft	$600
		Ceramic, Entrance	64	sqft	$400
		Hrdwd, Living/Dining	310	sqft	$1000
Trim	Upstairs Unit	Trim for new walls	86.5	Lnft	$300
	Dwnstrs Unit - Main Flr	Trim for new walls	42.5	Lnft	$100
	Dwnstrs Unit - Bsmnt	Trim for new walls	44	Lnft	$100
			Finishing Carpentry Subtotal		**$2,500**
Kitchen					
Install Kitchen	Upstairs Unit	Cabinets, counter, installation	1	each	$12,000
Range	Upstairs Unit		1	each	$1,000
Range Hood	Upstairs Unit		1	each	$300
Fridge	Upstairs Unit		1	each	$1,000
Dishwasher	Upstairs Unit		1	each	$500
Microwave	Upstairs Unit		1	each	$300
Dishwasher and Sink hook-ups	Upstairs Unit		2	each	$1,200
				Kitchen Subtotal	**$16,300**
		Construction Subtotal			**$41,400**
Correction Factor	Cost Overruns and Underestimation			1.2	$49,700
				PROJECT TOTAL	**$49,700**

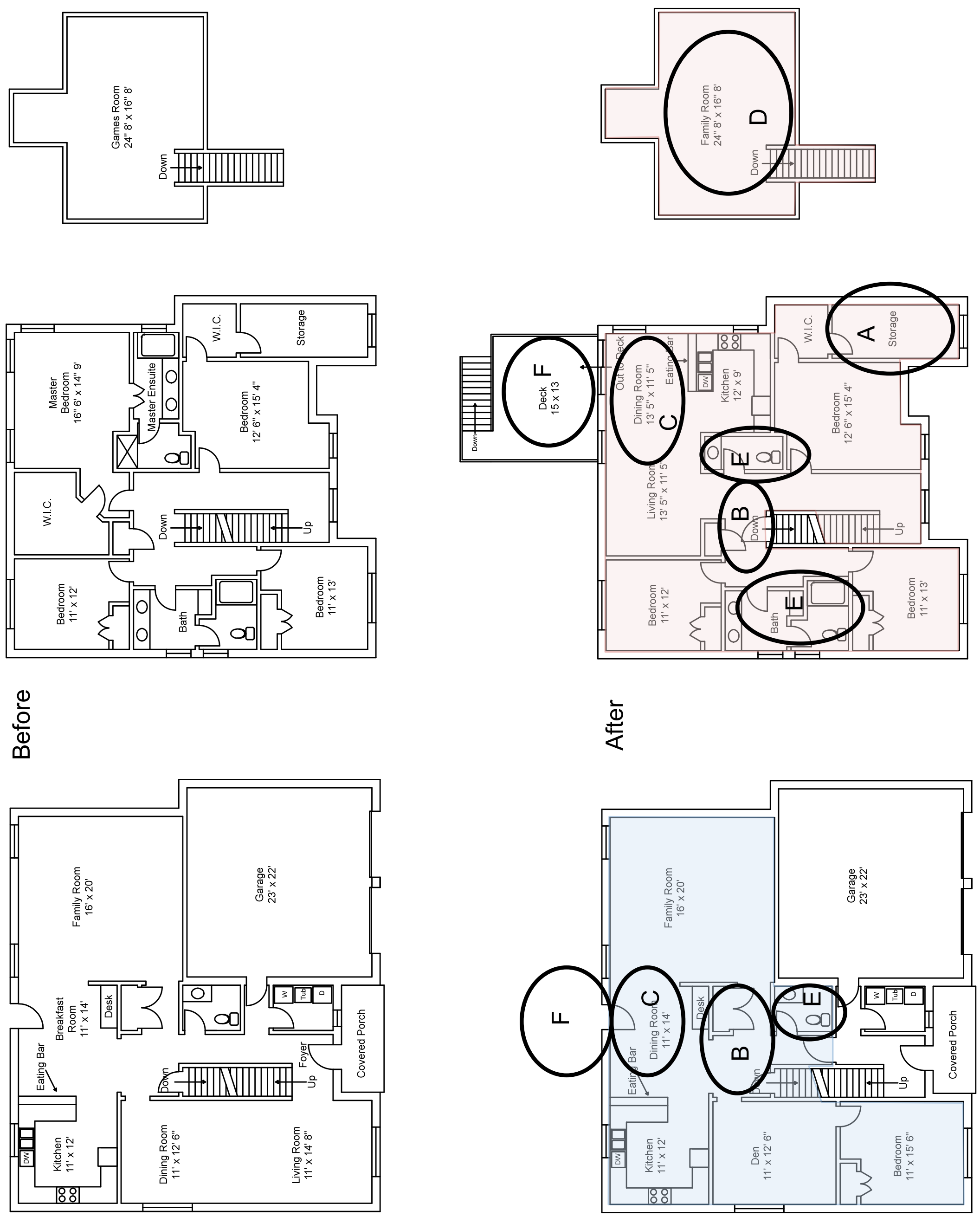


Figure 4.4: Key design features of the two-family conversion

Table 4.5: Design Details for the Two-Family Conversion

Location	Corresponding Design Guidelines	Explanation
A	17	Storage is important. This large storage space will be highly valued by the occupants of the upstairs unit. This space helped make this home a good candidate for conversion.
B	22, 23, 24, 25	Both entries are well designed. They can access both the private and public spaces in the home, they have just the right amount of space, and both have a nearby closet for storage.
C	31	Both units have only one dining room. Space is at a premium in conversions like this and since formal dining rooms are hardly used, it makes sense to only have one per unit.
D	33	This attic space was a key feature in making this home a good candidate for conversion. A second living space for an upstairs unit is often hard to create, so taking advantage of attic space is a good solution.
E	45, 46, 47	Bathrooms in both units are private but accessible and they have functional layouts. The main-floor unit would have a full bath in the basement.
F	49, 50	Both units have a good connection to the outdoors from the main living areas. Both are private and are big enough for a BBQ and a table for a family.

Table 4.6: Two-family conversion income scenarios

Income Source	Description	Amount		Final Project Cost	Simple Payback (Years)
		Grant	Rent*		
None	Apartment constructed for family member, no rent collected	N/A	N/A	$49,700	N/A
Apartment rental	Rent collected from tenants	N/A	$1,130	$49,700	3.7
RRAP Secondary/Garden Suite**	Grant from CMHC for construction cost and monthly rental	$24,000	$885	$25,700	2.4

*Average apartment rental amount from CMHC (2011) pg 20. This rental amount is the average rental rate for the Hamilton CMA
**RRAP grant from (CMHC, 2012)

4.1.3. Upstairs Apartment Conversion Example

This conversion takes a 3 bedroom, 2 ½ bathroom, 2167 square foot home and converts it into a 2 bedroom, 1 bath *apartment*, and a 3 bedroom, 1 ½ bathroom family home, called the *main floor unit*. The original home plan was adapted from O'Brien (1998) and the conversion was estimated to cost $48,500. There are several scenarios presented in Table 4.9 showing how this cost could be recouped with payback periods of between 2.5 and 4.5 years.

The main floor unit, shown in blue in Figure 4.5, takes advantage of the basement for additional space like the two family conversion did. Although not shown in the plan, many suburban basements have common features and uses. They generally house the utilities like the water heater, furnace, and electrical panel. They may also contain the laundry facilities, although in this case the laundry is on the main floor. Basements usually have the plumbing 'roughed-in' for a full 3-piece bathroom and have space for a family room with space left over. For this conversion it has been assumed that a family lived in the home long enough to construct a family room and install a full bathroom in the basement prior to the conversion. It is also assumed that the family room and bathroom only take up half the basement while the other half was left unfinished. In this conversion the remaining unfinished basement space has been converted into two bedrooms. A simple conversion of the main floor living room to a bedroom completes the construction of the downstairs unit. When complete, the main floor unit has a main floor family room, dining room, bedroom, den or office, kitchen and powder room and the basement contains the family room, primary bathroom, and two bedrooms. There are certainly other possible configurations and designs are not limited to what is shown here. Since the state of the basement is based on a likely scenario but depending on the actual state, more or less work may be needed. In either case the downstairs unit meets the special needs of a single family. Specific design features of the downstairs unit are explained in Figure 4.6 and Table 4.8.

The *upstairs apartment* is quite large and with its excellent outdoor space could easily house a young couple and a child or a home office. As with the other units, the upstairs apartment has been separated into public and private areas and has ample storage. It has been designed with adaptation and flexibility in mind. In the future, the unfinished room could be converted into a workshop, a home office, another bedroom, or any number of other uses. This allows the residents to expand later when funds arise or needs change. The upstairs unit does not have its own laundry facilities. There are several possibilities for the occupants to do laundry aside from using a laundromat. The laundry could be located in the unfinished room, but this could need costly plumbing work. The residents could also work out an arrangement to share the main floor unit's laundry facilities, as they are accessible right off the garage and it would not require entering the main floor unit. A locked door could be set up on the laundry room door that enters the main floor unit for privacy. Specific design features of the upstairs apartment are explained in Figure 4.6 and Table 4.8

Overall, this conversion shows how a homeowner can leverage extra space in their home to make a profitable apartment. The payback for the apartment is estimated at 2.5 to 4.5 years in the relatively modestly rental market in Hamilton, ON as shown in Table 4.9. More competitive markets could shorten payback periods further. This conversion also shows how excellent outdoor space and an unfinished space in the apartment allow for future flexibility.

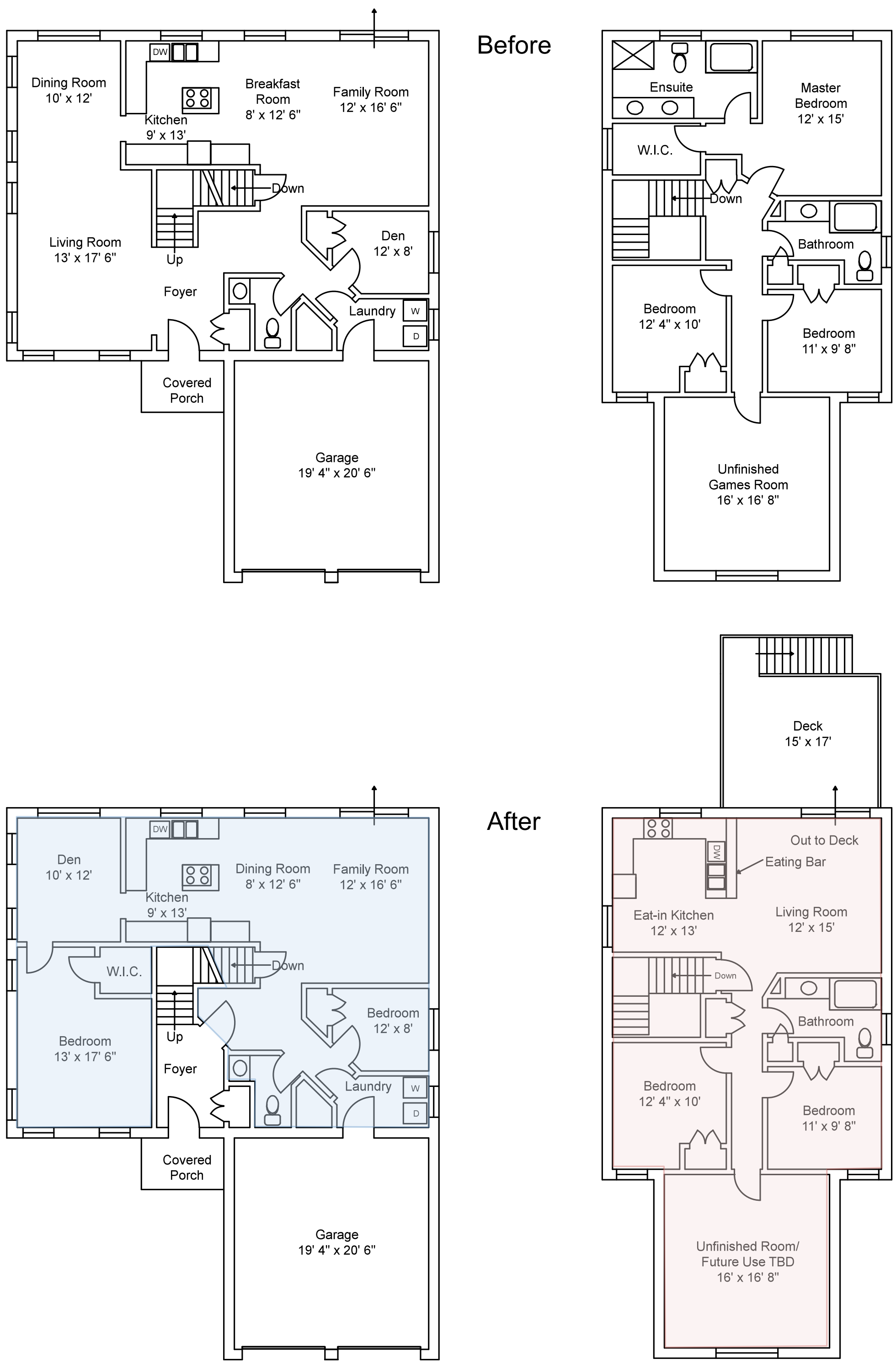


Figure 4.5: Top – Before; Bottom – After. Blue – Main floor unit; Red – Upstairs apartment

Table 4.7: Construction Cost Estimate for Upstairs Apartment

Construction Work	Dwelling Unit	Work Description	Quantity	Unit of Measure	Cost ($) CAD
Rough/General Carpentry					
Wall Demolition	Apartment	Open up master suite	300	sqft	$700
Wall Construction	Apartment	Build front hall closet	66	sqft	$600
	Prmry Unit – Mn Flr	WIC	84	sqft	$700
	Prmry Unit – Mn Flr	Close in Bedroom	148	sqft	$1,300
	Prmry Unit – Mn Flr	Entry Door Wall	36	sqft	$300
	Prmry Unit - Bsmnt	Bedrooms	368	sqft	$3,200
Door Removal	Apartment	Remove 4 Doors	4	each	$100
Door Construction	Apartment	Fire Door	1	each	$300
	Apartment	Sliding Door	1	each	$1,800
	Prmry Unit – Mn Flr	Fire Door	1	each	$300
	Prmry Unit – Mn Flr	Bedroom Door & WIC Door (install only)	2	each	$100
	Prmry Unit - Bsmnt	Install Bedroom Doors (install only)	2	each	$100
	Prmry Unit - Bsmnt	New Bedroom Doors	2	each	$400
Deck	Apartment	Outdoor Space	180	sqft	$2,700
Electrical	Both	Everything	1	Flatrate	$10,000
				Rough/General Carpentry Subtotal	**$22,600**
Finishing Carpentry					
Flooring	Apartment	Kitchen, front hall - ceramic	68	Sqft	$400
	Apartment	Living Room - Hrdwd	194	Sqft	$600
Trim	Apartment	Trim for new walls	47	Lnft	$200
	Prmry Unit – Mn Flr	Trim for new walls	60	Lnft	$200
	Prmry Unit - Bsmnt	Trim for new walls	44	Lnft	$100
				Finishing Carpentry Subtotal	**$1,500**
Kitchen					
Install Kitchen	Apartment	Upper and lower cabinets, counter	1	each	$12,000
Range	Apartment		1	each	$1,000
Range Hood	Apartment		1	each	$300
Fridge	Apartment		1	each	$1,000
Dishwasher	Apartment		1	each	$500
Microwave	Apartment		1	each	$300
Dishwasher and Sink hook-ups	Apartment		2	each	$1,200
				Kitchen Subtotal	**$16,300**
				Construction Subtotal	**$40,400**
Correction Factor	Cost Overruns and Underestimation		1.2		$48,500
				PROJECT TOTAL	**$48,500**

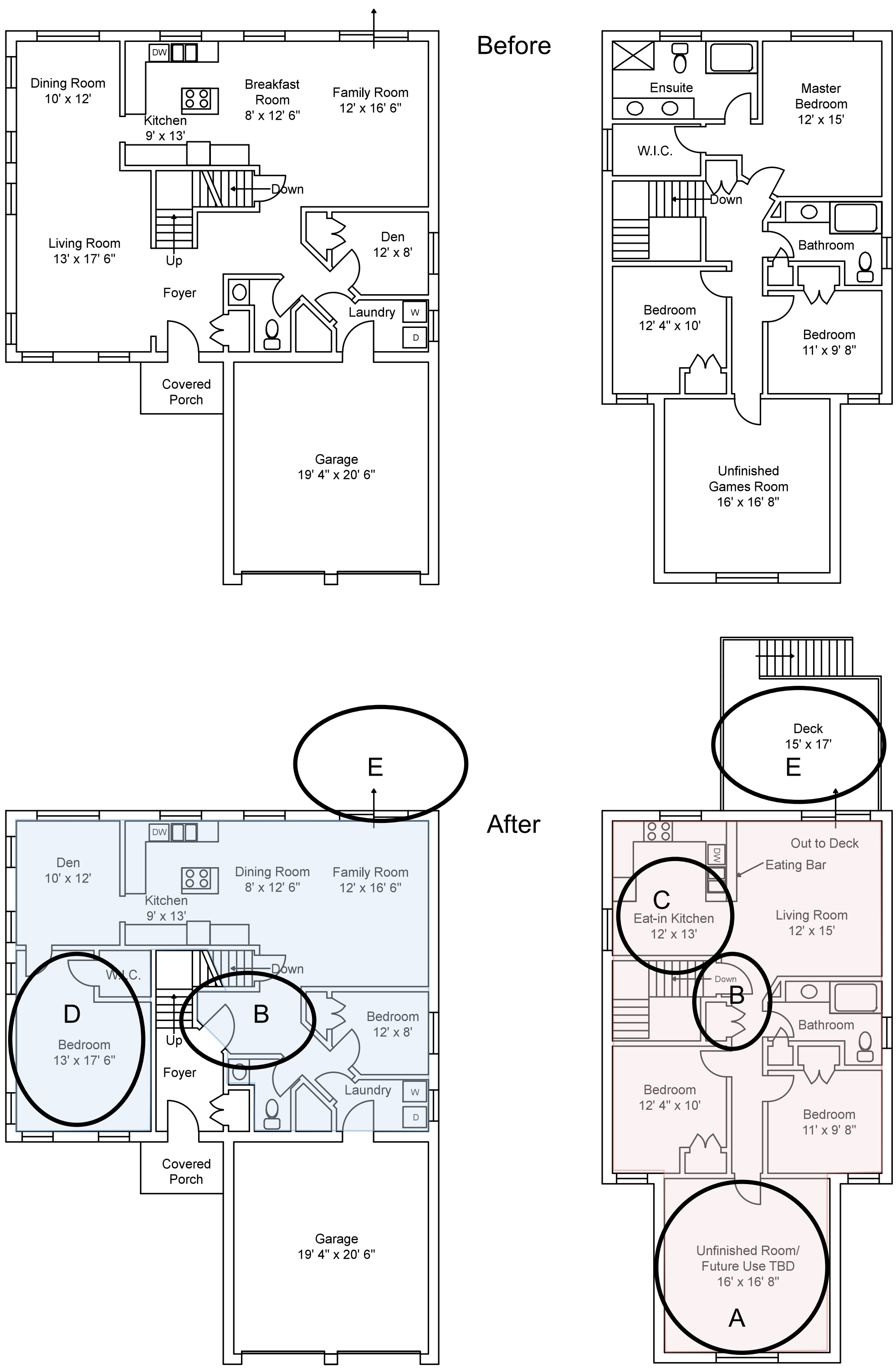


Figure 4.6: Key design features of the upstairs apartment conversion

Table 4.8: Design Details for Upstairs Apartment Conversion

Location	Corresponding Design Guidelines	Explanation
A	17	This large room could serve many purposes. As an unfinished room it could be used for storage, a workshop, or an artists studio. In the future is could be changed to serve many purposes, a large master bedroom with a small living space for example
B	9, 22, 23, 24, 25	Both entrances are appropriately sized and the upstairs apartment has a closet for storage. The primary unit entrance lacks storage space, in part due to the awkward geometry of the original layout. A wardrobe could be used a solution. Its small size will allow it to fit in this space but may limit storage.
C	32	This is a small eat-in kitchen, appropriate for a small table for two people. An eating bar has been provided to sit 3 people more comfortably. In the case of occasional company, a leafed table can be move to the living room and furniture temporarily moved.
D	45, 46	This bedroom is a generous size and has excellent natural light. However it is off the den and at the front of the home on the main floor. One or both of these features may be undesirable to some people. Solutions such as vegetation for privacy in front of the windows or using this space for another purpose and building more bedrooms in the basement are some solutions.
E	49, 50	Both units have excellent private outdoor space. The deck on the upstairs apartment could be used as a main entrance if desired.

Table 4.9: Upstairs apartment conversion income scenarios

Income Source	Description	Amount		Final Project Cost	Simple Payback (Years)
		Grant	Rent*		
None	Apartment constructed for family member, no rent collected	N/A	N/A	$48,500	N/A
Apartment rental	Collect rent from tenants	N/A	$885	$48,500	4.5
RRAP Secondary/Garden Suite**	Grant from CMHC for construction cost and monthly rental	$24,000	$885	$24,500	2.3

*Average apartment rental amount from CMHC (2011). This rental amount is the average rental rate for the Hamilton CMA
**RRAP grant from (CMHC, 2012)

4.1.4. Common Spatial Barriers to Dividing Suburban Homes

Table 4.10 and Figure 4.7 show some of the barriers to dividing homes. These barriers are spatial, related to the layout of the home, not to social or legal issues. These barriers do not stop a home from being divided, they just make it more difficult. With enough money, almost any space issue in the home can be overcome. These barriers are not the only ones encountered when dividing suburban homes, but are some of the most common that were encountered when trying to create the example divisions.

This example assumes that the floors will split the home, similar to the *two-family conversion* and *upstairs apartment* conversion. One unit will occupy the ground floor and basement, while the other unit occupies the upstairs. The *in-law suite* example shows how to overcome some of these issues, but there are drawbacks and limits to what can be done.

Table 4.10: Explanation of Common Spatial Barriers to Dividing Suburban Homes

Barrier	Name	Explanation
A	Stranded Rooms	The library in this home has been cut off from the rest of the home by the stairs and foyer, or 'stranded'. Even if a wall was taken down, the library cannot connect with any other room besides the garage. This makes this room difficult to incorporate into a divided home, especially if floors divide the units. The question arises: which unit would this room belong to? But also: Who would want to cross a shared entry to access a room in their home? Stranded rooms are barriers for this reason. Ways to work around this could be to create a new main entrance for one of the units or turn the library into a shared space like a laundry room or an office for a home business for one of the units.
B	Awkward Stairs	This stair design poses barriers for two reasons. First is that they are in the middle of the downstairs public space and land in the middle of the home. When dividing units by floors, stairs in the middle of the home make access to the upstairs unit difficult. Secondly, if you look at where they go up and down, the upward stairs are away from the entrance. This means that an upstairs unit needs to cut in front of the downward stairs to access their unit. The question then arises: who gets the down stairs portion of the home? In the dividing examples, the main floor unit depends on the basement for space. If residents can't access the basement this can pose a problem.
C	Open to Below/Vaulted Ceilings	The "open-to-below" space is rather small in this home, but in some homes it can be large. An upstairs railing may overlook entire rooms in some designs. When dividing by floors, these need to be cut off for privacy reasons or else the upstairs unit would look down on the main floor unit. This means that extra walls need to be built to close them off or a floor would need to be built over the 'open' space. The option of building a wall means that the upstairs will have less space, while the option of building a new floor is expensive.
D	Mixing Public and Private Areas	The entrance of any home is a public area and therefore should be directly part of the public area or at the very least have equal access to the private and public zones. You should not have to go from the entrance through the private bedroom areas to get to the public living spaces. In divisions, the top of the stairs are often the entrance to the upstairs unit and should meet this same criteria. When using the master suite to create the living, dining, and kitchen spaces, stairs at the front of the home and a master suite at the back can be a problem, like in this example.

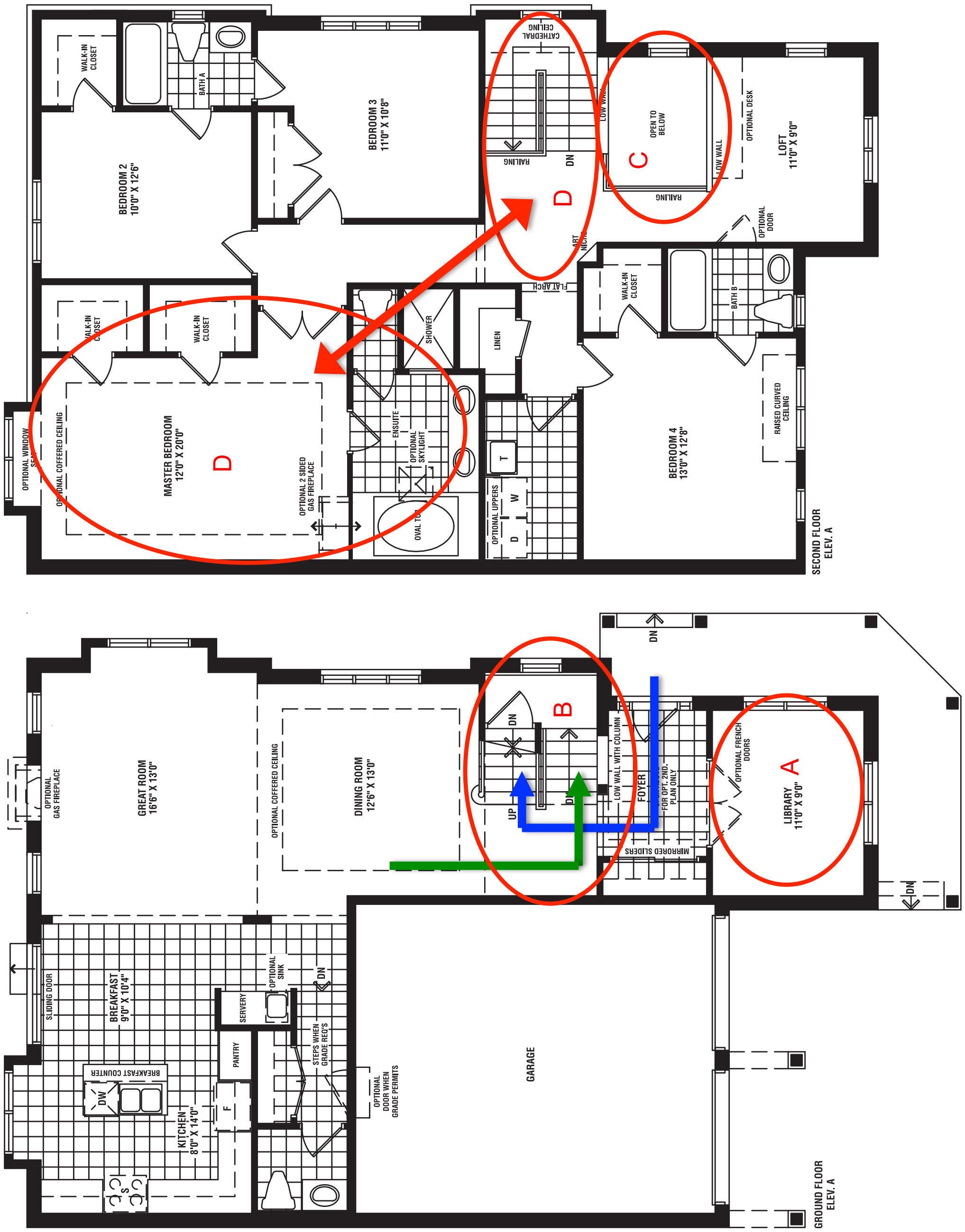


Figure 4.7: Common design features that pose barriers to dividing suburban homes

4.1.5. Dividing Homes User Interface Development

The user interface needs to explain to the user the goal of the module, how it accomplishes this, and how to use the module. An excel spreadsheet was used with text boxes for explanation and hyperlinks to link users to the content developed in Sections 4.1.1, 4.1.2, 4.1.3, and 4.1.4. Users will simply read the explanations and examples and attempt to apply the ideas to their own home. This tool is not comprehensive so a list of recommended readings that explain more about home design as well as tools to evaluate their redesigns has been provided (ex. the slow home test). Figure 4.8 shows the screenshot of the module interface with identification of the important features. The blue print indicates a link to the material developed above. Figure 4.9 shows the process flowchart the user would go through in order to use and complete the module.

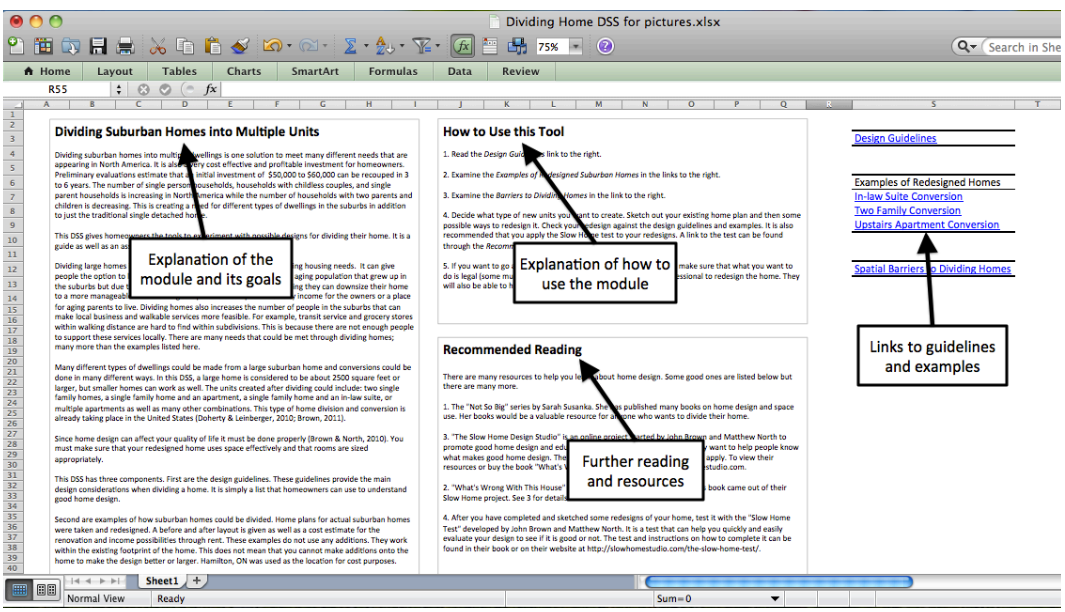


Figure 4.8: Dividing suburban homes module screenshot

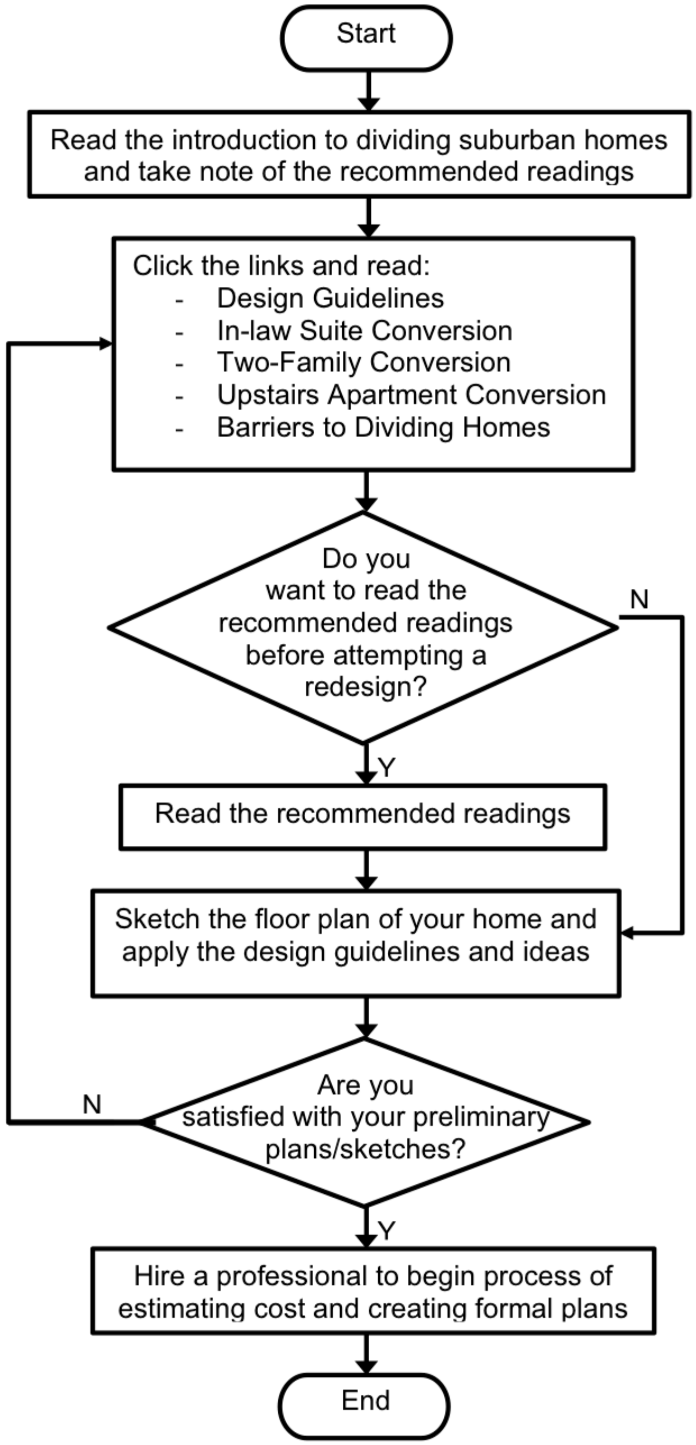


Figure 4.9: Flow chart of how a user would use the dividing suburban homes module

4.2. SUSTAINABLE ADDITIONS MODULE DEVELOPMENT

The sustainable additions module only recommends building methods and materials for the structural walls of the addition as explained in Chapter 3. The three building materials selected for recommendation are: straw bale, rammed earth and adobe. For further details on these building materials see Section 3.5.

4.2.1. Sustainable Building Material Selection

Harris (1999) and Anderson et al. (2008) argue there are great difficulties when rating building materials for environmental performance. Broadly, Anderson et al (2008) identify the problem as one where each building is unique and as such the criteria for rating building materials will differ from project to project. Furthermore they argue that the knowledge of the environmental impacts of various activities is growing at a rapid rate and is changing the values placed on various environmental impacts and thus sustainable building material selection. In particular Harris (1999) argues that the main problem is that "there are no established set of indicators, no agreed system for weighting indicators against one another, there are few existing criteria for individual indicators and there are few targets for individual indicators". To sum, there is not an accepted way to universally rate the environmental performance of one building material over another and if there was, this method would need constant updating. This difficulty has not stopped many organizations from developing rigorous rating systems or requirements for green building and the following organizations show it can be done well. Green building organizations such as BRE (Harriss, 1999; Anderson et al., 2008), the Living Building Challenge (McLennan & Brukman, 2010) and the Canada Green Building Council (2009) have systems for rating buildings and building materials. The requirements and rating criteria change between systems.

A rating methodology and system was needed to select sustainable building materials. The rating methodology as well as the particular indicators (or criteria) of sustainability employed here have been adapted from Harris (1999) and Friedman (2007). This rating system uses life-cycle analysis (LCA) when choosing weights. Due to the complicated nature of weighing and comparing indicators against each other they have all have been given equal weights similar to the methods of Harris (1999) and Friedman (2007).

It has been assumed that all methods are built to the highest standards in terms of thermal performance and that high-quality materials and construction standards have been used. This ensures all the methods perform relatively equally in thermal performance (insulation), are low-maintenance, and have long lifespans. These are common criteria in green building material selection but since they rate similarly they have been excluded as selection criteria from the decision matrix. All the methods here can be built on the same type of foundations and can support the same types of roofing systems.

The outcome of the comparison of the building materials is shown in Table 4.11. With the chosen methodology it is clear that straw bale, adobe, and rammed earth, environmentally outperform the other materials and methods that are often considered sustainable. Table 4.12 and Table 4.13 give details on the criteria and building methods used in Table 4.11.

Table 4.11: Decision Matrix for Sustainable Building Material Selection

Building Method* / Criteria*	Stick-Frame	Insulated Concrete Form	Insulated Structural Panel	Straw Bale	Adobe	Rammed Earth
Embodied Energy	2	2	2	3	3	3
Resource Conservation	1	1	1	3	3	3
Extraction Impacts	2	2	2	3	3	3
Indoor Toxicity	3	2	3	3	3	3
Recyclability	2	1	1	3	3	3
Ease of Construction	3	2	3	1	1	1
Cost	3	2	3	2	2	2
Total (/21)	16	12	15	18	18	18
Scaled (%)	**76**	**57**	**71**	**86**	**86**	**86**

- Ratings range from 1 to 3; 1 = Poor Environmental Performance; 3 = Excellent Environmental Performance
- Each criterion was weighted equally. For example, Recyclability was deemed to be just as important as Resource Conservation
*See Table 4.12 and Table 4.13 for more information on criteria and building methods respectively

Table 4.12: Explanation of Criteria Used in Selecting Sustainable Building Materials

Criteria	Explanation
Embodied Energy	Embodied energy takes into account the energy required to produce a material including procurement (extraction, mining, etc), transportation and manufacturing, but not labour.
Resource Conservation	Considers if the resource is renewable at current rates of production.
Extraction Impacts	How disruptive is the extraction to local ecosystems? Considers if the impacts are negative, neutral, positive, or reversible.
Indoor Toxicity	Some building materials contain substances that are harmful to humans and can cause health problems.
Recyclability	Can the materials used be easily recycled and how much waste is produced?
Ease of Construction	Takes into account both the complexity of the building method and if there are builders and practitioners widely available to construct with this material or method. Methods that are easier to build with can be cheaper or more easily completed.
Cost	Relative to the other construction methods, how much does this method cost to construct?

Table 4.13: Notes and Details on Building Materials

Building Materials/Method	Explanation
Stick-Frame	Assumes a wall system of: vinyl and/or brick veneer cladding, OSB sheathing, 16 inches on centre stud frame, fiberglass insulation, and drywall. Non-FSC wood. Super insulated.
Insulated Concrete Form (ICF)	Assumes a wall system of: brick veneer, ICF, and drywall. ICF contains concrete core sandwiched between extruded insulating foam.
Insulated Structural Panel	Assumes a wall system of: vinyl and/or brick veneer, ISP, and drywall. ISP is an extruded foam core sandwiched between OSB sheathing.
Straw Bale	Assumes load-bearing construction. Wall system is straw bales plastered with earth-based plaster. Location is close to agricultural areas to supply straw bales.
Adobe	Assumes home is built in area that needs no added insulation, local soils are used for construction of adobe bricks and plaster and that soil can be sourced locally.
Rammed Earth	Assumes home is built in area that needs no added insulation, local soils are used for construction of walls and that soil can be sourced locally.

4.2.2. Creating the Sustainable Material DSS

After selecting the materials to recommend and reviewing the climates and locations where they can be built the DSS was created. The DSS will show users how the materials were selected, tell them where these building materials can be used, and give them basic information on these building materials as well as resources so they can learn more if needed.

Appendix D shows the final module that will be given to users as well as the information sheets, or primers, for straw bale, adobe, and rammed earth. An example of a primer is shown in Figure 4.13. The DSS offers an information document that shows homeowners where the building materials can be used based on climate and resource availability. Figure 4.10 shows the flow diagram of how the DSS guides the user through a decision process for selecting their building material. Since there is an extensive amount of design and engineering that must go into the construction of an addition, this module does not perform design calculations. What it does do is advocate for sustainable material selection while giving users the knowledge of where they can build these structures and where they can get more information. The responsibility of final structural design falls on the homeowner to source appropriate contractors, engineers, and architects.

There is an obvious connection between this module and the dividing suburban homes module. If the layout is being altered by a large addition the dividing suburban homes module contains useful information applicable when completing an addition. There is also a connection to the reducing the home's environmental impact module. If homeowners are interested in using sustainable building methods and materials, they may also be interested in exploring options for reducing the environmental impact of their home. Formal connections built into the DSS between modules will be explored later in this chapter.

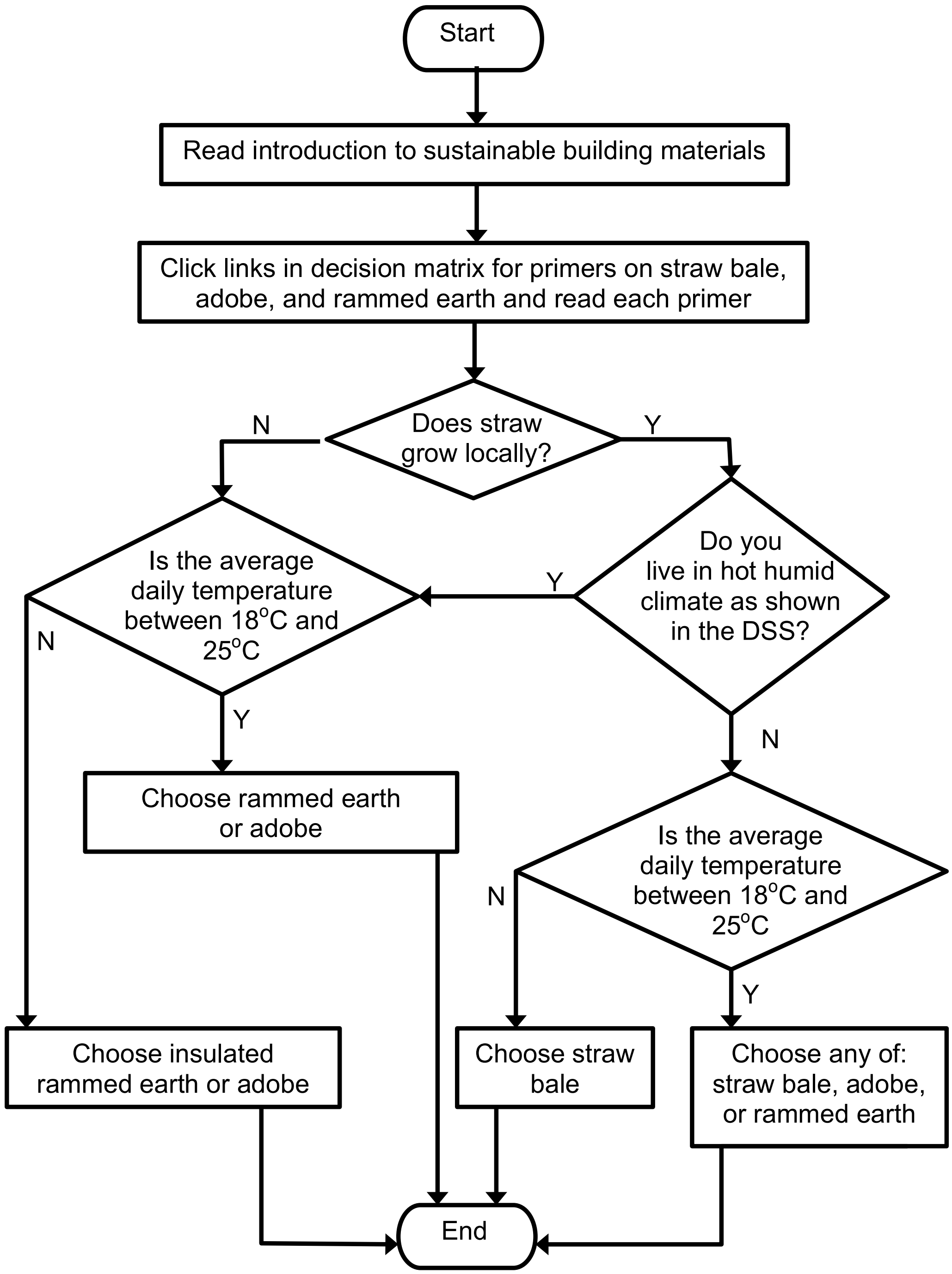


Figure 4.10: Flow chart for the sustainable building materials module

4.3. Reducing the Home's Environmental Impact Module Development

The Reducing the Home's Environmental Impact Module (EI Module) contains a large number of small tactics that can be used to reduce the environmental impact (EI) of the home. Recall that the tactics were divided into three categories: water use (potable), stormwater/yard management, and energy use. Also recall that strategies to reduce the home's EI were based primarily on structural changes to the home, not behavioural change. The water use category contained the following tactics: low-flow fixtures, rainwater harvesting, on-site grey water reuse, composing toilets, and on-site wastewater treatment. The energy use category contained: passive solar heating, natural ventilation for cooling, natural lighting, solar water heating, solar PV, insulation, and energy efficient landscaping. The stormwater category contained: rainwater harvesting, soakaway pits, yard ponding, rain gardens (bioretention), and permeable paving. Each tactic is explained in detail in the primers in Appendix E.

These tactics will not all be applicable to all homes. The home's site conditions including solar access, soil type, and a homeowner's future plans, among other factors, will limit, constrain or determine the use of the tactics. In addition to these case-specific constraints, there are general constraints since some of the tactics are mutually exclusive. Thus a decision support system needs to be created to determine which tactics are appropriate for specific situations based on homeowner inputs. Also noted from research is that there are certain baseline conditions that a homeowner should meet before implementing any tactics within a category. These are simple but necessary conditions to meet.

Upon investigation it was evident that while each category (water use, energy use, and stormwater/yard management) is related in some way to the others, each has its own unique constraints and should be treated in separate streams. After analyzing the tactics and their constraints, a list of questions answered by homeowners seemed the most appropriate approach to screen various tactics. Each category must also inform the homeowner of the baseline conditions and an explanation about why the category is important and how it can reduce the EI of their home. Recall Section 3.6 explained the relevance of each category in reducing the EI of their home.

The development of each category in the EI module is outlined below and Figure 4.11 shows the flow chart of how the process for the EI module works. Note that the water use category not only outlines the development of that category but is also demonstrates the model used to create all three categories.

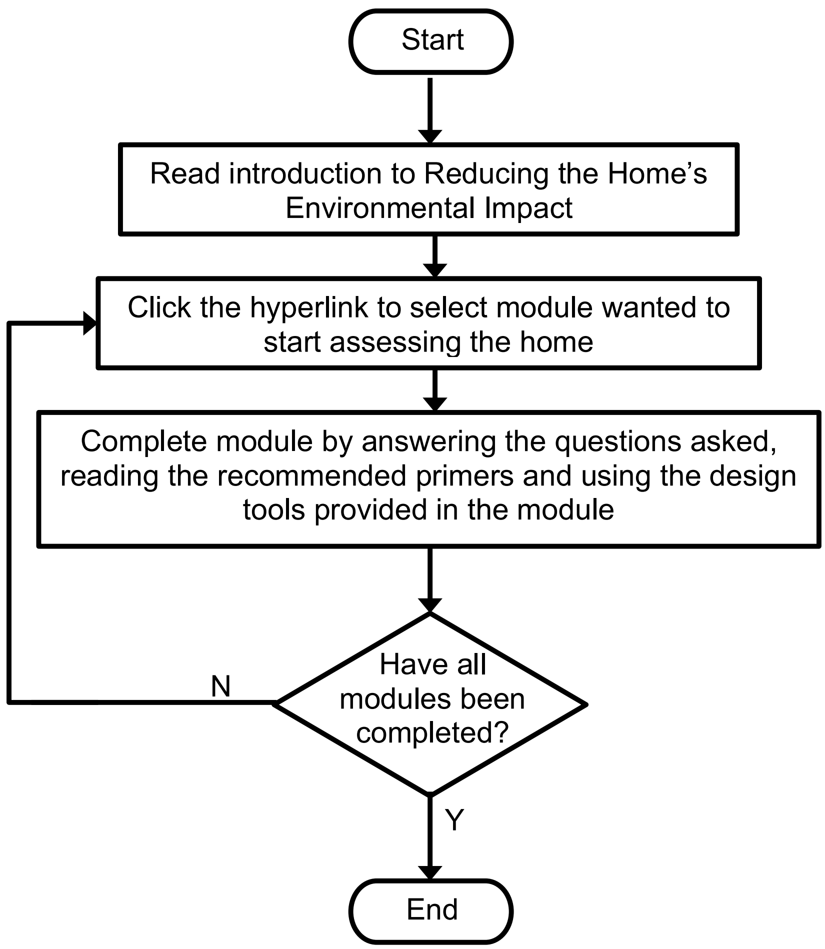


Figure 4.11: Flow chart showing the process used for the environmental impact module

4.3.1. Water Use (Potable) Tool Development

The water use category advocates for the use of low-flow fixtures, rainwater harvesting, grey water reuse, composing toilets, and wastewater treatment. The baseline condition is that the home must use low-flow fixtures. There are no mutually exclusive uses within these tactics. On the contrary, they are all complimentary. These tactics can be implemented anywhere in North America where by-laws permit. The only question the homeowner needs to answer is if they are planning on renovating in the near future. This is because each tactic requires plumbing to be run through the home. This can be quite expensive and is best timed with another renovation when the home's walls will already be opened up.

Rainwater harvesting, grey water reuse, and wastewater treatment each require professional designers to implement. There is little technical design help that can be given to the homeowners that will be of value. However the rainwater harvesting cistern or barrel can be sized and the homeowner, with the help of a tool can estimate the amount of water it can supply. Thus the water use tool will have the homeowner indicate if they plan to renovate, inform them of the baseline conditions, explain the importance of reducing water use, explain the basics of each tactic, and help them size a rainwater harvesting system.

Excel was chosen as the platform since it is widely used and versatile enough to allow for interactive inputs by users and links to other sources if required. Figure 4.12 shows a screenshot of the water use tool showing what it looks like and how it conveys the important information to the user. Also included are 'primers'. These primers are sources of additional information for users and an example is shown in Figure 4.13. It was decided that since there was already a significant amount of published material on all the tactics in all the categories, it was unnecessary to recopy that information in this tool. Instead, users are given these primers that explain the basics of the tactic, given visual and design aids, and direction to sources of additional information. It is expected that after completing the EI module, users will have a preliminary list of tactics they want to explore further and will read these sources of additional information. This was used as model and template for both the stormwater management and energy use categories as well.

Some of the tactics, such as rainwater harvesting, have sizing or design tools that accompany them. Figure 4.12 is a screenshot of the layout of the water use reduction tool. The text boxes indicate important components of the interface. The user simply clicks the link and they are guided to a tool to help them further design this tactic. The calculations behind these design tools can be found in Appendix F and the primers in Appendix E.

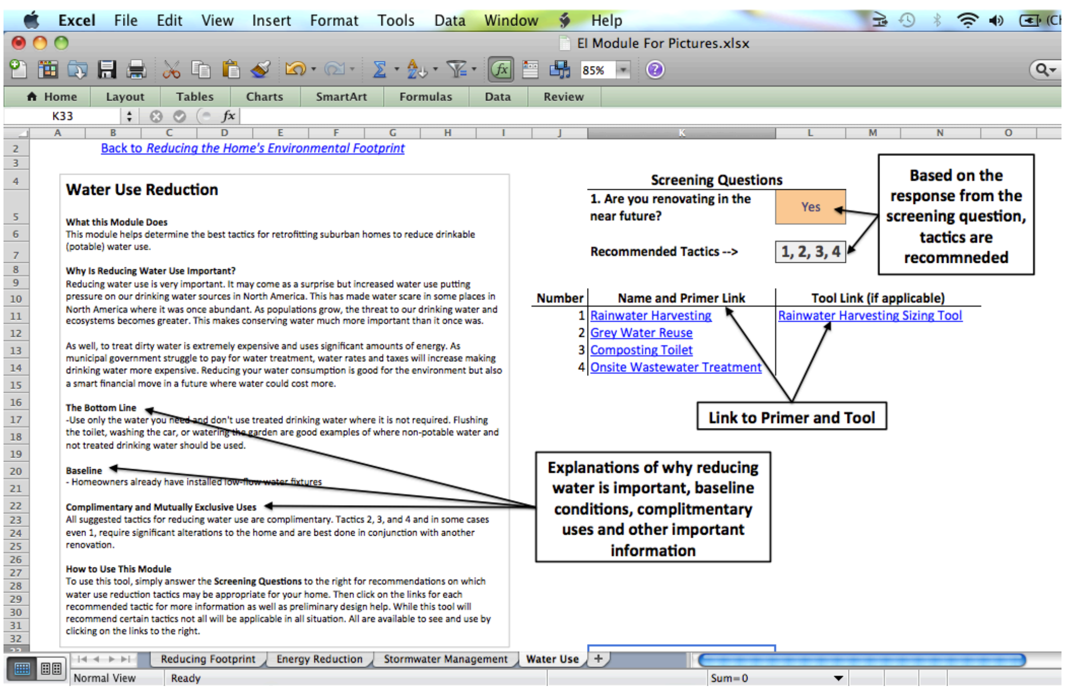


Figure 4.12: Water use reduction interface

Energy Efficient Landscaping

Introduction

Vegetation planted in specific spots outside the home can help reduce energy consumption. They can help cool in the summer and reduce heat loss in the winter. Plants can help cool in two main ways. First they can shade and block sunlight and heat from getting in the home. Secondly they can create a pocket of cool air around the home. This is done through evapotranspiration. This is why a forest is often cooler than a field. In addition to helping keep the home cool, trees and plants can help keep the home warm by acting as windbreaks, blocking cold winter winds.

General Notes Cooling With Vegetation

Large trees can provide excellent shade in the summer. But in the winter even deciduous trees can still shade the home and reduce wanted passive heating (McPherson & Rowntree, 1993). Fortunately there are some deciduous trees that can let in enough sunlight to still passively heart the home. The tree selection tool can help identify desirable trees. For shade, place plants on the east and west but not on the south. Unless the climate is very warm and little winter heat is needed, use overhangs on the south to block summer sun. See the shading and overhang tool for information on overhangs.

Bushes or trees that branch out from the base of the tree are good because they provide even shade coverage and are more predictable. Vines can be trained along trellises to provide a shaded canopy as well as aesthetic appeal. (Buckholder & Anderson, 2005)

Further Reading

- Buckholder, P. & Anderson, C. (2005). Be cool: Natural systems to beat the heat. *Home Power, 108,* 20-25
- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light*. New York: John Wiley & Sons, Inc.

Design Considerations
For Cooling

- Don't block breezes – breezes help keep the home cool
- Plants can decrease cooling requirements by 17-57% (Buckholder & Anderson, 2005; Brown and DeKay, 2001)
- Try and have the tree canopy cover at least 20% of the property
- Shade all air conditioners and paved surfaces - this is very important (South Carolina Energy Office, n.d.; McPherson & Rowntree, 1993)

For Windbreaks

- Plant a dense foundation of evergreens around the home complimented by windbreaks and hedges further out
- Windbreaks can provide 5-15% heat savings (McPherson & Rowntree, 1993)
- Windbreaks have a "wind-shadow" (can block wind for a distance) of 2-4 times their height (Brown & DeKay, 2001)
- Evergreens are best for windbreaks

Photo: A row of north-facing dense shrubs provides a windbreak against cool winter winds while trees on the east and west shade during the summer

Figure 4.13: Example of a primer used to convey basic information to users

4.3.2. Energy Use Tool Development

The energy use category advocates for the use of passive solar heating, natural ventilation for cooling, natural lighting, solar water heating, photovoltaics (PV), insulation, and energy-efficient landscaping. The baseline condition is that the homeowners already use energy efficient appliances and fixtures. There are no mutually exclusive tactics and most are complimentary. The screening questions consist of four questions:

1. Is your home well insulated?
2. Is there a south-facing wall on your home that is exposed to the sun in the winter?
3. Do you need a new roof?
4. Do you have a place on your property (preferably your roof) that is south facing and exposed to the sun for most of the day all year long?

These questions are able to screen out any tactics that will not work based on homeowner plans or the site conditions of the home.

Similar to the water use category, the energy use category gives the homeowner primers so they can better understand the various tactics. However, unlike the water use category, the energy use category has plenty of design tools to help the homeowner with preliminary design, sizing, and assessment of the impact of the various tactics. Figure 4.14 is a screenshot of the tool interface. An example primer is shown in Figure 4.13. The calculations behind these design tools can be found in Appendix F and the primers in Appendix E.

4.3.3. Stormwater/Yard Management Tool Development

The stormwater category advocates for the use of rainwater harvesting, soakaway pits, yard ponding, rain gardens (bioretention), and permeable paving. The baseline condition is that the homeowners do not use synthetic or chemical fertilizers on their yard. There are mutually exclusive uses in this category; yard ponding and soakaway pits are not used together. On the other hand, rainwater harvesting and lawn naturalization are complimentary. The only screening question asks if the homeowner uses water outdoors and/or gardens. This determines if rainwater harvesting is appropriate or if other tactics should be suggested.

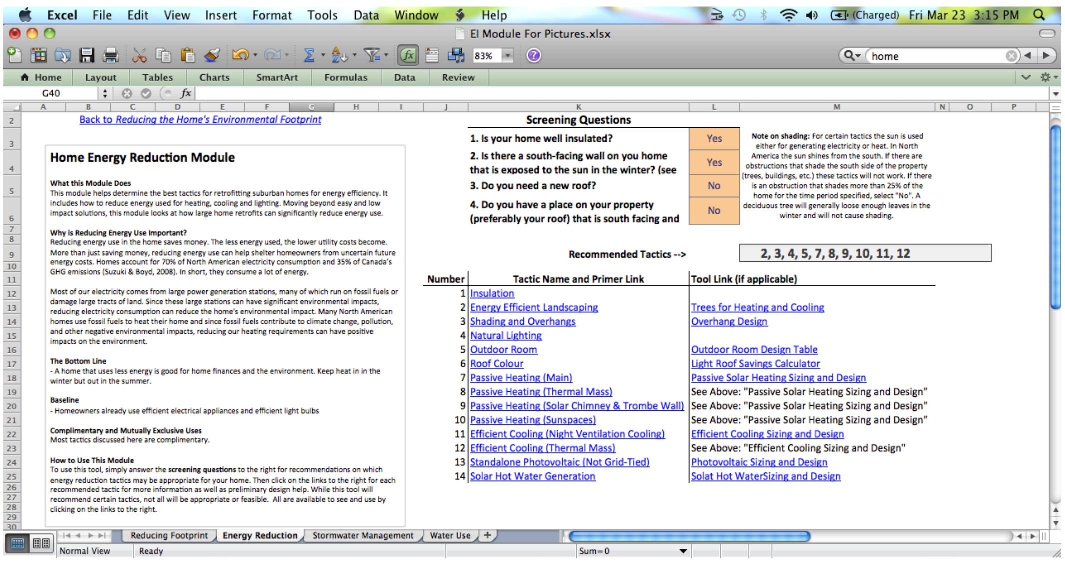


Figure 4.14: Energy use module interface

Similar to the water use category the stormwater management category gives the homeowner primers so they can better understand the various tactics. The stormwater category has plenty of opportunity to help the homeowner with preliminary design, sizing, and assessment of the impact of the various tactics. Figure 4.15 is a screenshot of the tool’s interface, the list of primers, and the tactics that have associated tools. An example primer is shown in Figure 4.13. The calculations behind the design tools can be found in Appendix F and the primers in Appendix E.

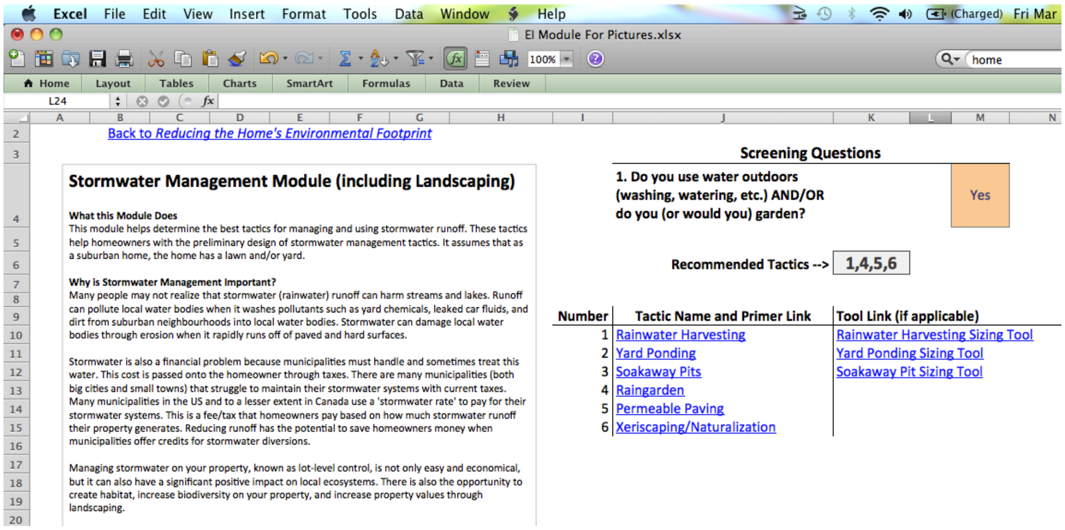


Figure 4.15: Stormwater management tool interface

4.3.4. Integration of Environmental Impact Categories

The three categories have been developed on their own and can be run separately, but homeowners should use all three if they want to maximize the tool's ability to help the reduce the EI of their home. There is no obvious way to integrate the three categories with the current excel platform other than to run each one on its own, although after running the three categories homeowners may make their own connections between the modules based on what they learn and their preferences and plans. These connections will vary and generally be case specific and so have not been incorporated into the EI module.

Figure 4.16 shows the screenshot of the user interface of the Reducing the Home's Environmental Impact Module. This page explains, much like the previous categories in this chapter did, how the tool works and what the different categories mean. The links to the different categories are shown in Figure 4.16 and each category links back to the main page. This allows users to complete each category and then navigate back to the main page to complete another category.

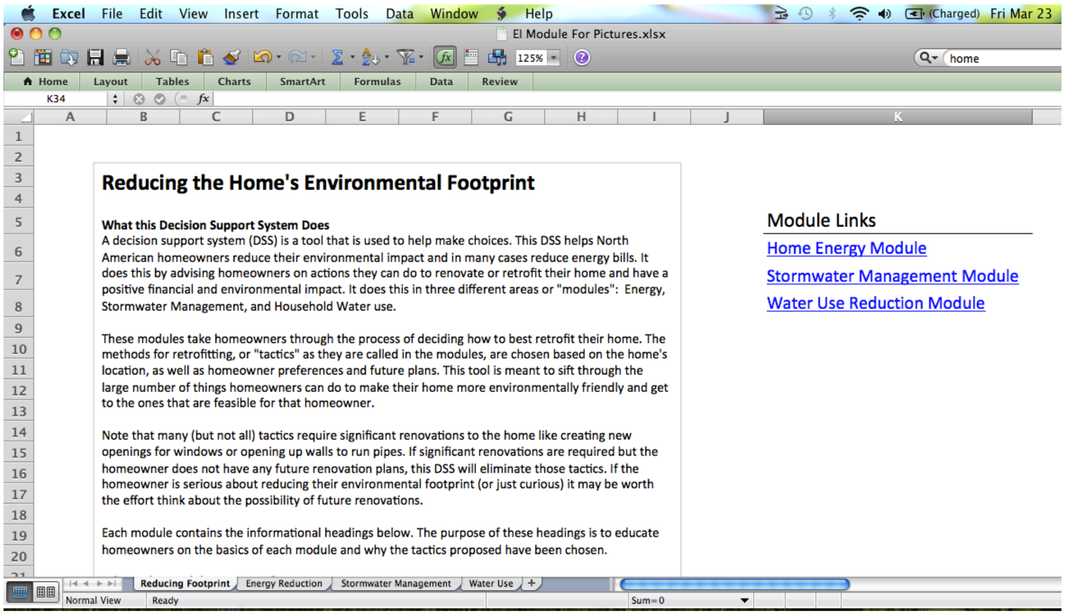


Figure 4.16: Reducing the home's environmental impact module interface

4.4. MODULE INTEGRATION

Now that each module has been explained and developed in detail, they can be linked together in an integrated tool. The degree to which the three modules are integrated is very much dependent on the user's preferences and the integration is quite simple. It consists of an explanation to the user about how the three modules are related. Examples are used to illustrate when users should explore more than one module. Figure 4.17 shows the user interface of the DSS main page and how the information is conveyed to the user. It explains how the tools can be used separately or together in an integrated fashion. Users simply click the link to the module they want to use and that module will be automatically opened. Due to the complexity of navigation when in use, links back to the main DSS page are not provided from each module, although the DSS main page will not close when a module is selected

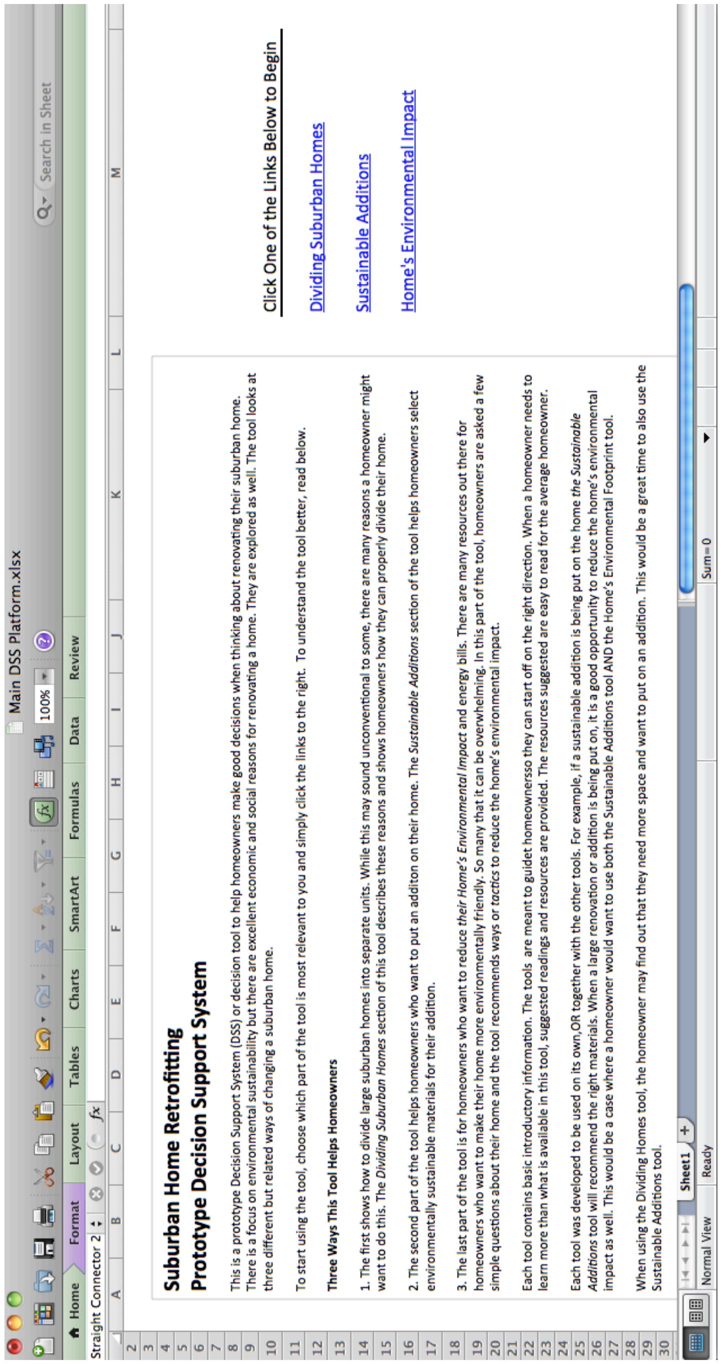


Figure 4.17: DSS main page interface

Upon completion of the detailed development of the DSS, a useful exercise would be to apply it to suburban homes. This would show how the DSS works in terms of inputs, outputs, and design assistance. Chapter 5 demonstrates the application of the DSS, detailing the use of each module. Through this application conclusions can be drawn and further steps better recommended.

5. DSS APPLICATION

5.1. APPLICATION INTRODUCTION

Application examples will be completed in this chapter showing how the DSS can be utilized. There are three modules, Dividing Suburban Homes, Sustainable Additions, and Reducing the Home's Environmental Impact, and while application examples will be shown for each, the Reducing the Home's Environmental Impact will be explored in the most depth. The application of the Dividing Homes module has largely been developed and explored in Section 4.1. Similarly, the Sustainable Additions Module simply gives a recommendation on building material based on location and there is no extensive design work involved. Following the process outlined in Figure 4.10 several locations will be explored for the type of material appropriate for additions. The result is that the only module left to be tested in depth is the Reducing the Home's Environmental Impact.

5.1.1. Dividing Suburban Homes Application

Recall that to use this module, users must first read the spatial design guidelines that make recommendations for how to use space in a residential home. These design guidelines aim to make the divisions of livable spaces that are functional for the long-term and contribute to the quality of life of the occupants. Second, users read through and examine the examples of redesigned homes. These homes are representative of large suburban homes and a user can explore how they can be divided and converted into multi-family dwellings. Lastly, users read over the document relating to barriers to dividing homes to learn about common spatial features of suburban homes that can make dividing difficult. The user interface for this module can be seen in Figure 4.8.

To explore the examples of the application of the guidelines, refer to Section 4.1. The in-law suite conversion in Section 4.1.1 is an example of a home that has been divided into two units, one for a family and one for an elderly single or couple. Figure 4.1 shows the before and after depiction of the home's floorplan and how space was used. The in-law suite could be used as an apartment and the financial implications of this are explored in Table 4.3. This example shows how the constraints of working within the existing footprint can affect meeting some of the guidelines and how tradeoffs will have to be made.

Section 4.1.2 is an example of applying the guidelines to create two dwellings suitable for two families. Each unit is given enough space such that there are two living areas, a connected kitchen-living-dining room area, and access to private outdoor space. A before and after depiction of the floor layout can be seen in Figure 4.3. This example shows that there are many options for dividing homes to meet the needs of the occupants and that there are certain features that should be incorporated into a division while others can be designed to meet the specific needs of the occupants.

The final example applying the guidelines can be seen in Section 4.1.3. This division shows how a home can be converted into an apartment to generate extra revenue and how this income can be realized quickly with short payback periods. This application also advocates for adaptability by keeping some rooms unfinished or their use unconstrained. This allows the unit the ability to cater to the different needs of different populations.

It is readily seen through this application that dividing large suburban homes into multiple units can achieve a number of goals. It can reduce the environmental impact of the home by housing more people in less space which reducing heating costs and resource requirements per capita. It also caters to the need of a variety of populations who need different types of housing beyond the large single family home. This contributes the to resilience of the local community. There are clearly a number of options for dividing suburban homes to create a number of different types of dwellings.

5.1.2. Sustainable Additions Application

As previously shown in the development of the Sustainable Additions Module, this module advocates for the use of straw bale, adobe, and rammed earth construction for additions based on the home's location. The tool is not complicated and simply uses a screening of local resources and climate to determine which building method to recommend. The user needs to answer the following to decide on a material:

1. Does straw grow locally?
2. Is the average daily temperature between 18°C and 25°C?
3. Is the climate hot and humid?

The flow chart in Figure 4.10 shows the decision process for using this module. Table 5.1 was created based on the recommendations made in the Sustainable Additions Module. The locations chosen are representative of all possible outcomes of the questions above for North America. Any location chosen in North America will answer the questions in the same way as of the locations shown in Table 5.1 and come to the same conclusion.

Table 5.1: Recommended Building Materials in Representative Locations

Location	Local Straw?	Average Daily Temperature Between 18°C and 25°C?	Hot and Humid?	Recommendation*
St. John's, NL	N	N	N	Insulated rammed earth or insulated adobe
Phoenix, AZ	N	Y	N	Rammed earth or adobe
Toronto, ON	Y	N	N	Straw bale
Los Angeles, CA	Y	Y	N	Straw bale, rammed earth, or adobe
Miami, FL	Y	Y	Y	Rammed earth or adobe

*rammed earth and adobe recommendations are not insulated unless otherwise indicated

The application of this module is relatively simple. After learning about the various building materials it is a trivial exercise to answer the questions and determine the recommended building material. The challenge is not the application of the module but rather the subsequent design and research required to go about creating the actual addition.

5.1.3. Reducing the Environmental Impact Module Application

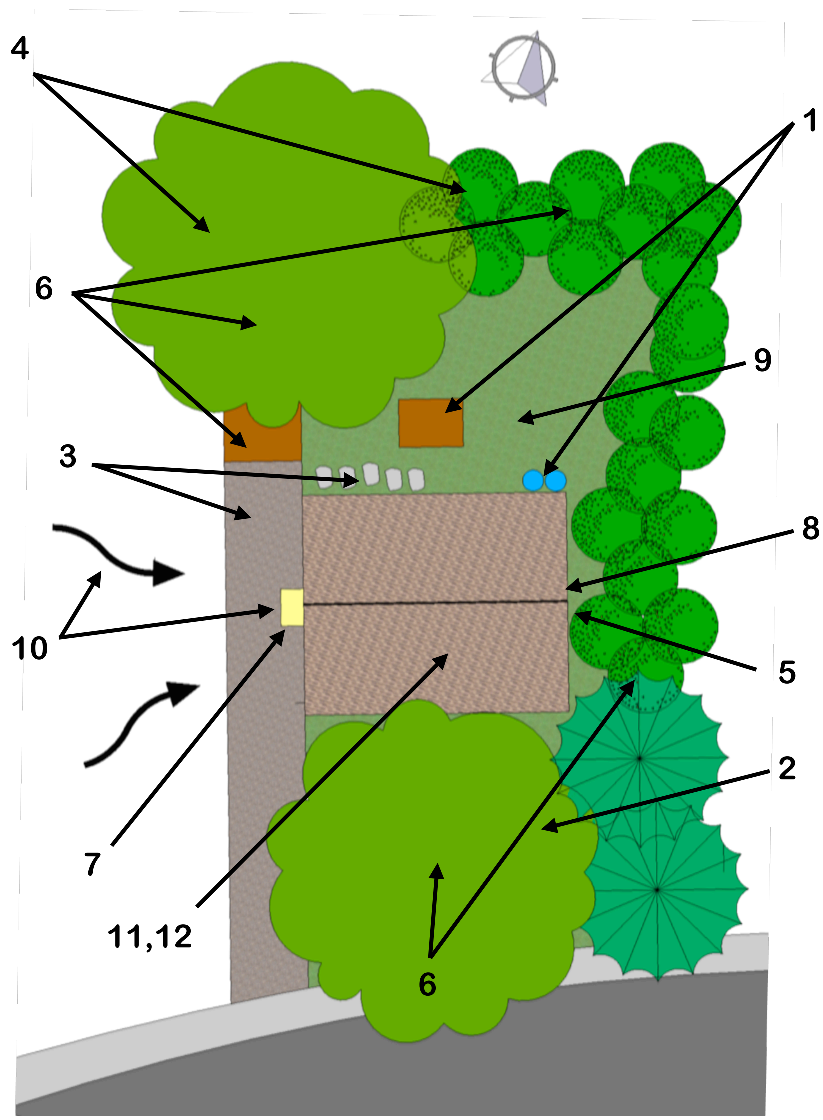
Three homes were chosen for application of this module with the goal of showing outcomes of the application to homes of various ages and styles. The first and earliest home was built in the 1950's and is representative of a post-war suburban home. The second home was built in 1990 and is typical of suburban homes built in the Greater Toronto Area (GTA) in that era. The third home is the two family conversion used as an example in the application of the dividing homes design guidelines shown in Section 4.1.2.

5.2. Application to a Post-War Suburban Home

The post-war suburban home used as an example can be seen in Figure 5.3. It originally had one bathroom and three bedrooms. No additions have been put on the home and the front of the home faces south. The stormwater management category was completed first, followed by the water use, and energy use categories. Figure 5.1, shows an overview of all the recommendations for post-war home example.

5.2.1. Stormwater Management Application

The stormwater management section asks only one question: Do you use water outdoors (washing, watering, etc.) AND/OR do you (or would you) garden? The answer here was "Yes", the homeowners maintain a vegetable garden that needs regular watering. With this information the DSS suggests rainwater harvesting, rain gardens, permeable paving, and naturalization/xeriscaping as possible tactics to reduce the home's environmental impact.



1 – Rainwater harvesting
2 – Rain garden
3 – Permeable Paving
4 – Naturalization
5 – Insulation
6 – Energy Efficient Landscaping
7 – Shading and Overhangs
8 – Natural Lighting
9 – Outdoor Room
10 – Efficient Cooling
11 – Photovoltaics
12 – Solar Hot Water

Figure 5.1: Post-war Home Recommendations Overview

Rainwater Harvesting

The homeowners already use rain barrels to harvest water for their garden. The rainwater harvesting sizing tool was used to evaluate their current system. The inputs to this tool are: location, size of catchment area, daily water use, and desired reliability of the system. The location is Hamilton, ON, the catchment size is half the roof and measures 35 m^2, and the daily water use was estimated at 50L/day. The maximum reliability of this system is 63%. Reliability is a measure of how often there will be water in the barrel when needed and is constrained by location, roof area or catchment area, and daily water use. The tool, shown in Figure 5.2, determined that for desired reliabilities of 50%, 60% and 63%, the barrel would need to be 172L, 326L, and 587L respectively. The system currently has a capacity of 410L. This confirms that the homeowner already has adequately sized barrels for the catchment area. Note that the orange cells in Figure 5.2 require user input while the grey cells are outputs. This convention has been used throughout the entire DSS.

Rain Gardens

Rain gardens were suggested for this home. The front of the home drains onto the front lawn that is steeply sloped to the road, regularly draining onto the road. A rain garden could stop unwanted runoff but the slope could pose significant drainage problems. A tiered system may be suitable but likely expensive and possibly ineffective. This would be a case where the homeowner would read the recommended readings further to see if a rain garden would be suitable for their unique front yard. If a rain garden is not suitable and diverting rainwater away from the front yard is wanted, a downspout could be run to the backyard to the rain barrels, to pool, or to a rain garden.

5.2.2. Stormwater Management Application

The stormwater management section asks only one question: Do you use water outdoors (washing, watering, etc.) AND/OR do you (or would you) garden? The answer here was “Yes”, the homeowners maintain a vegetable garden that needs regular watering. With this information the DSS suggests rainwater harvesting, rain gardens, permeable paving, and naturalization/xeriscaping as possible tactics to reduce the home’s environmental impact.

Rain Cistern Sizing Tool

Input	Value
City/Location	Hamilton
Average Rainfall Volume (mm)	9.05
Averge Time Between Rainfalls (days)	3.49
Roof/Capture Area (sq m)	35
Runoff Coefficient	0.95
First Flush Depth (mm)	0
Daily Water Use (L/day)	50
Desired Reliability (%)	60

Output	Value
Maximum Reliability (%)	63.3
Required Barrel Size (L)	325.7

Figure 5.2: Screenshot of the rain cistern sizing tool with user inputs and generated outputs for post-war home

Figure 5.3: Post-war suburban home used in application example

Permeable Paving

It was apparent that the property was in little need of increased permeable surfaces. As can be seen in Figure 5.3 and Figure 5.1, the driveway is gravel and pervious. However, it is sloped to the road and in a heavy rain would contribute water and sediment to the storm sewer system. The homeowners could investigate other options for paving such as lattice pavers. The shed in the backyard seen in Figure 5.1 and Figure 5.3 drains onto the yard. There are no other impervious surfaces in the backyard.

Yard Naturalization

The yard is already very naturalized in comparison to other suburban homes. Overall there is not a significant amount to be done to increase naturalization. Incrementally increasing the number of native flowers, bushes, plants, and trees and eliminating non-native species would reduce the artificial lawn in the back yard and increase valuable biodiversity. This would attract more pollinators that would be beneficial to the vegetable garden. This is another case where the further readings would be of help to the homeowners in selecting plants and design strategies that would be appropriate and low maintenance.

5.2.3. Water Use (Potable) Application

The water use category only asks one question: Are you renovating in the near future? Since running new plumbing for water recycling or treatment and can be expensive, it is best combined with a planned renovation where walls will already be opened up. The answer to this question was “No”, there are no renovations planned. Although the answer was “No”, the cost of running plumbing in this home may not be prohibitive since unlike many new suburban homes (see Figure 4.1, Figure 4.3, and Figure 4.5), the plumbing in this home is run in a single stack and is contained to the ground floor and an unfinished portion of the basement. It may be feasible to run new plumbing in this situation. However, the answer will remain the same for this example. The only recommended tactic in this case is rain water harvesting. This would displace potable water used for watering outdoors. For details on rainwater harvesting as they pertain to this application, see Section 5.2.2.

5.2.4. Energy Use Application

The energy use category is much more complex than the stormwater or water use categories. There are four questions in this category and the answers for this case are as follows:

1. Q: Is your home well insulated? A: No
2. Q: Is there a south facing wall on your home that is exposed to the sun in the winter? A: Yes
3. Q: Do you need a new roof? A: No
4. Q: Do you have a place on your property (preferably the roof) that is south facing and exposed to the sun for most of the day all year long? A: Yes

Support was given for questions 1 for judging insulation levels, and for 2 and 4 for judging sun exposure. With these answers the following tactics were recommended to the homeowner for further investigation. That investigation is explained in the next sections:

a) Insulation
b) Energy efficient landscaping
c) Shading and overhangs
d) Natural lighting
e) Outdoor room
f) Efficient cooling (night-ventilation cooling)
g) Standalone photovoltaic (not grid-tied)
h) Solar hot water generation

Insulation

The home is not well insulated. The homeowners recognize this but indicated that fixing this problem is not planned due to related costs and the disruption it would cause. The tool recommends reading the insulation fact sheet published by the US Department of Energy (2008). The fact sheet recommends insulating the attic to R60, the walls to R27, and the floor to R30 for this climate. In this case, when adding insulation is not desired, homeowners can opt to buy their energy from a renewable energy supplier who guarantees that the energy purchased is renewable.

Energy-Efficient Landscaping

The primer recommends trees to block the wind on the windward sides on the home. In suburban areas winds are already reduced due to the neighbouring houses. In this case the prevailing winds are predominately from the northwest. Thick cedars and a large slope on the north and a large slope, a shed, and a willow on the northwest shield the home. In terms of reducing heat loss the landscaping and surrounding features do a good job already.

Interpreting the primer in terms of cooling, the backyard is heavily vegetated with trees and shrubs. A very large tree shades the south in the summer as seen in Figure 5.3. The east is shaded year round by cedars while the west is not shaded. This is not a bad situation as the homeowners noted that the large tree in the front does an excellent job of shading in the summer while letting the sun in the front window in the winter.

However, improvements could be made for cooling in three ways. First the cedars on the east could be removed or trimmed down to make room for a deciduous tree. This tree would loose leaves in the winter increasing the passive solar potential but would still shade in the summer. This is undesirable since the cedars provide a privacy barrier and habitat for birds, both of which are valued by the owners. On the west a tree could be planted for shade but this would require removing a portion of the driveway, which is not an option. The tree in the south is not optimal since it would still block some sun in the winter and could be cut down and overhangs used instead. This again was not an option since the homeowners appreciate the large tree for many reasons and the cooling benefits may in fact outweigh the passive solar benefits. Thus no further action is needed on the home in terms of shading and wind blocks from vegetation.

Shading and Overhangs

The primer recommends using shades and overhangs on the east, south, and west windows to block the high, hot summer sun but let in the low winter sun. Due to the shade provided by the trees on the east and south, overhangs are not required in these directions. There is a single westward window that could be shaded with an overhang. Using the Overhang Design Tool an overhang for this window was sized at 1.3m. The inputs and output from the Overhang Design Tool can be seen in Figure 5.4.

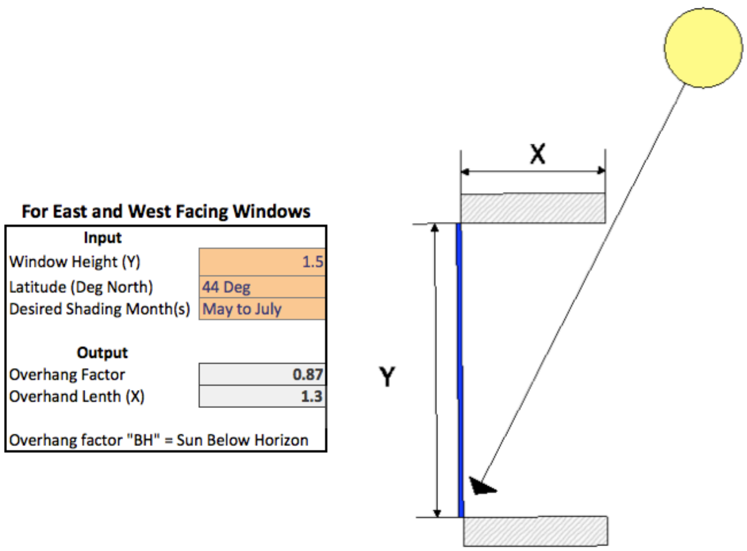


Figure 5.4: Screenshot of the overhang sizing tool with user inputs and generated outputs for post-war home

Natural Lighting

The home's footprint is such that each room has access to an exterior wall. The homeowners have installed large windows in a number of locations and noted that they rarely use artificial lighting during the day. No further work is required in this area.

Outdoor Room

The homeowners have sufficient space indoors and do not need any additional outdoor space. As an exercise the outdoor room design table, shown in

Appendix F, was consulted to see where the best place for an outdoor room would be if one was needed. The design table requires determining the wind direction relative to the sun and generally classifying the summer and winter climates. The wind is perpendicular to the sun and the summer climate is humid and temperate while the winters are cold. The winters are too cold for an outdoor room, thus only a summer outdoor room would be needed. According to the design table for a humid and temperate summer climate the outdoor room should to be shaded from the summer sun but not blocked from cooling breezes. A location that could meet these criteria would be the back yard of the home.

Efficient Cooling (Night Ventilation Cooling)

The efficient cooling primer explains that night ventilation is a way to cool the home by flushing out hot air at night and replacing it with cool air. Then, during the day the home is closed up and shaded to keep as much of the cool air in as possible. This process is repeated each day to keep the home cool. This tactic comes with a sizing tool that estimates the daily heat gain, recommends a type of ventilation cooling, and then determines the cooling power of that method.

Figure 5.5 shows the inputs and outputs for the cooling strategy selection. The homeowner selects their location from a dropdown menu, in this case the closest location was Niagara Falls. The tool then fills in the outdoor design temperature and relative humidity. These are the conditions the cooling system needs to be able to handle. They are 29.4^{o}C and 42% RH in this case. The homeowner then fills in the average climatic conditions for their location. These values can be obtained from Environment Canada or NOAA in the US. The tool includes detailed instructions on how to locate this data. From these data the tool outputs a design point and average daily condition lines on the Cooling Strategy Selection Chart shown in Figure 5.5. The design point is the large black dot. Whichever box(es) it falls within on the chart indicates the type of ventilation cooling strategies that can keep the home cool. In this case natural, fan or stack cooling, high thermal mass, thermal mass with night cooling, and evaporative cooling all appear adequate. Natural, fan or stack cooling is the cheapest so it would be selected and in this case the average daily conditions get cool enough to use cool night air for cooling as indicated by the average daily lines shown in the chart.

The next step requires estimating the cooling load or daily heat gain of the home in the summer. A heat gain estimation tool is included and Figure 5.6 shows the inputs and outputs from this tool for the post-war home. The heat gain is estimated at 146,000 kJ or 146 MJ per day. Since this tool was built for a well insulated home, this heat gain is likely a conservative estimate and factors like the large tree in the front yard will also affect this estimate. This information may be interesting to the user but likely not of much use. However the tool needs this information to size a ventilation cooling system and the user is instructed to move onto the next step.

The next step is to size a ventilation system as described in the primer. In this case it would simply be strategically-placed windows to allow airflow through the home. This home already has one windward and several leeward windows relative to the prevailing winds to take advantage of moving air. The inlet or windward window has an area of $1.25m^2$ as shown in Figure 5.7. The average wind speed for the area is 11.7 km/h according to Environment Canada. The wind is perpendicular to the window and the location is suburban. The maximum indoor temperature and a minimum outdoor temperature have been estimated using the average conditions for July in the area (see Figure 5.5). Based on these values the flush time, or the time to remove all the excess heat accumulated during the day from the home, is 2.8 hours. This is likely an underestimation since the home is not well insulated and the temperatures have been estimated and as the indoor temperature decreases and the outdoor temperature increases (the most likely scenario) the flush time increases. This tool also assumes that the flow of air reaches most of the home. The more of the home the airflow reaches the better the estimated flush time and effectiveness of the cooling. Regardless of the limitations, it can be seen that 2.8 hours is a very short period of time when compared to the length of the night. Thus even if the flush time is doubled to 5.6 hours, it will still be able to cool the home. It can be concluded that the existing placement of windows will provide the night cooling necessary in this climate if the windows are opened each night.

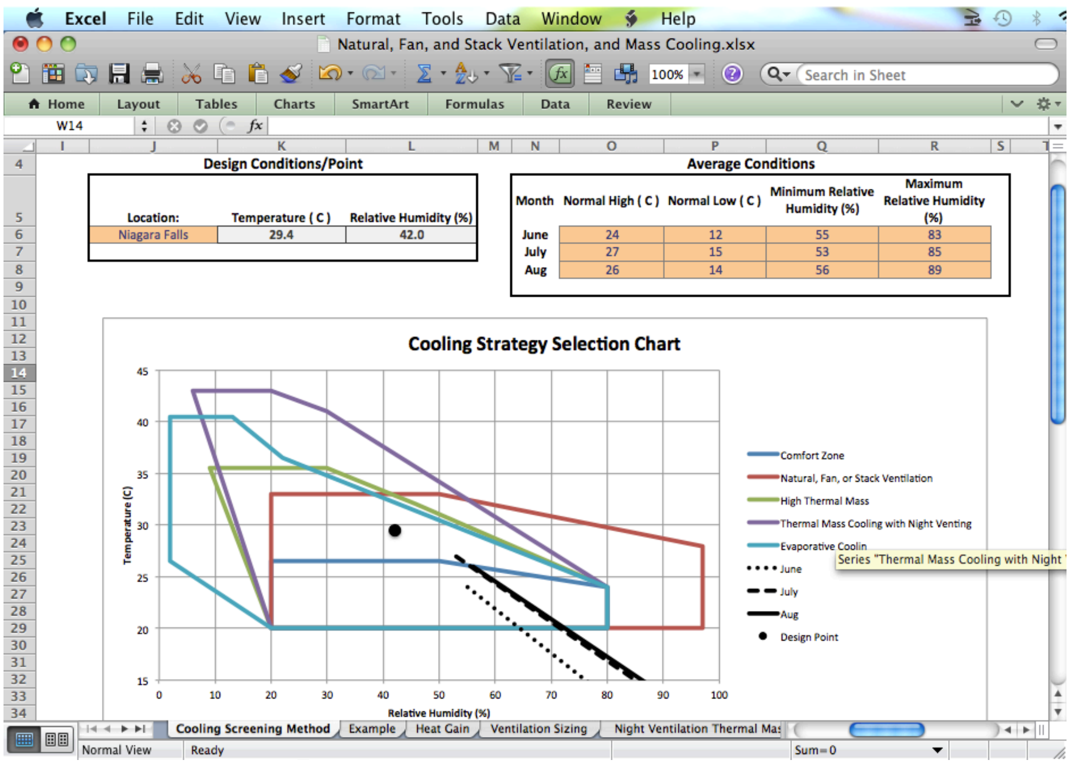


Figure 5.5: Screenshot of cooling strategy selection tool for post-war home

Heat Gain Calculation Tool

Location		Niagara Falls	
Design Temperature		29.4	
Heat Gain Sources			
		Area	**Heat Gain**
Total Exteriror Wall Area (square meters)		140.6	249
Roof Area (square meters)		96.2	544
Outside Door Area (square meters)	**Location**	**Total Area**	**Heat Gain**
	North	2.8	13
	NE & NW	0	0
	East & West	0	0
	SE & SW	0	0
	South	1.8	12
Window Area (square meters)	**Location**		
	North	6.2	197
	NE & NW	0	0
	East & West	8.6	327
	SE & SW	0	0
	South	4	139
		Area	**Heat Gain**
Infiltration		164	364
		Number	**Heat Gain (W)**
Number of People in the Home		2	135
Number of Lightbulbs		23	26
Appliance Gain (W)			410
Heat Gain Totals			
Total Sensible Heat Gain (W)			2416
Total Latent Heat Gain (W)			483
Peak Daily Heat Gain Rate (W)			2899
Total Daily Heat Gain (kJ)			146134

Figure 5.6: Screenshot of heat gain estimation tool with user inputs and generated outputs for post-war home

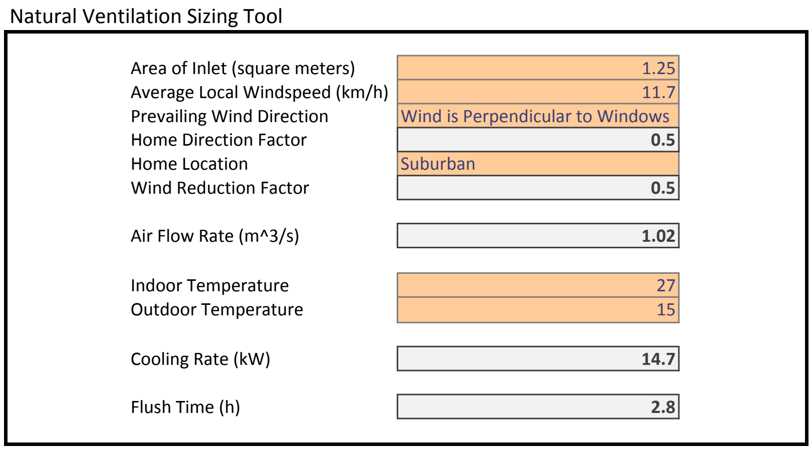


Figure 5.7: Screenshot of natural ventilation sizing tool with user inputs and generated outputs for post-war home

Standalone Photovoltaic (not grid-tied)

The photovoltaic tactic includes a tool for the preliminary sizing of a non-grid-tied photovoltaic system. This means the system does not feed back into the main grid but powers the home by itself using battery storage, known as an off-the-grid system. This requires dramatic decreases in energy use by the homeowners. The tool (shown in Figure 5.14, Figure 5.15, Figure 5.20, and Figure 5.21) allows the users to calculate their energy usage and then estimate the size of PV system they need. In this case the homeowners already knew their energy usage and the estimation of the home's electrical load could be bypassed. Using a panel output rating of 180W, the closest location built into the tool's menu, Toronto, and a load of 14.5kWh/day it was calculated that the homeowners would need 15 panels in June and 39 panels in December to meet 100% of their current needs. Using a 24V battery system and storage time of 3 days (the length of time the system may need to go without sun) the system would need to have a power rating of 474 amp hours and 1218 amp hours for June and December respectively. This estimate includes losses and necessary conversions from DC to AC current.

Solar Hot Water Generation

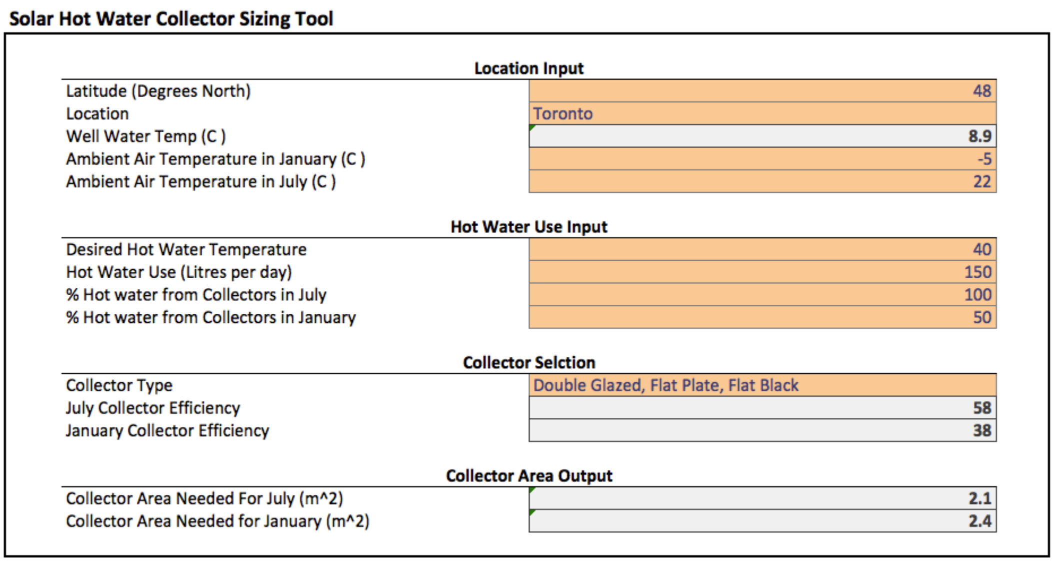
The solar hot water primer speaks to the fact that solar hot water generation is one of the most cost-effective energy saving systems to use. The accompanying sizing tool helps owners estimate the size of the system they need to meet their hot water usage. Figure 5.8 shows a screenshot of the tool including the inputs and outputs for the post-war home. The ambient temperatures were taken from Environment Canada. The desired temperature, hot water use, and percent of water from the collectors in July and January are recommendations from the tool's original print source (Stein & Reynolds, 2000). The double-glazed, flat plate, flat black collector panel was chosen from the drop down menu for its good efficiency performance in the home's climate. As seen in Figure 5.8, the homeowners would need to install 2.1m^2 of panels to meet 100% of their needs in July and 2.4m^2 of panels to meet 50% of their needs in January.

5.2.5. Post-war Suburban Home Concluding Remarks

With this assessment of this Hamilton, Ontario home it can be seen that while the tool recommended a number of tactics, not all were applicable due to site-specific constraints. Most tactics were applicable and due to the conscientious homeowners, a number of recommended tactics were already employed such as rain barrels, energy efficient landscaping, and night ventilation. The outputs from the various sizing tools demonstrate to the homeowners in a physical and tangible way what it would take to lessen their energy use.

5.3. APPLICATION TO A 1990'S SUBURBAN HOME

The 90's suburban home used for the example application can be seen in Figure 5.10. It is a 3600 square foot, 5 bedroom home built in 1990 and is located in the Greater Toronto Area (GTA). It is representative of suburban homes built in this era. No additions have been put on the home and the front of the home faces south. The stormwater management category was completed first, followed by the water use, and energy use categories. An overview of all the recommendations for the 1990's suburban home example are shown in Figure 5.9.



Solar Hot Water Collector Sizing Tool

Location Input	
Latitude (Degrees North)	48
Location	Toronto
Well Water Temp (C)	8.9
Ambient Air Temperature in January (C)	-5
Ambient Air Temperature in July (C)	22
Hot Water Use Input	
Desired Hot Water Temperature	40
Hot Water Use (Litres per day)	150
% Hot water from Collectors in July	100
% Hot water from Collectors in January	50
Collector Selction	
Collector Type	Double Glazed, Flat Plate, Flat Black
July Collector Efficiency	58
January Collector Efficiency	38
Collector Area Output	
Collector Area Needed For July (m^2)	2.1
Collector Area Needed for January (m^2)	2.4

Figure 5.8: Screenshot of solar hot water collector sizing tool with user inputs and generated outputs for post-war home

5.3.1. Stormwater Management Application

The stormwater management section asks only one question: Do you use water outdoors (washing, watering, etc.) AND/OR do you (or would you) garden? The answer was "Yes", the homeowners maintain gardens that need regular watering. With this information the DSS suggests the homeowner investigate rainwater harvesting, rain gardens, permeable paving, and naturalization/xeriscaping.

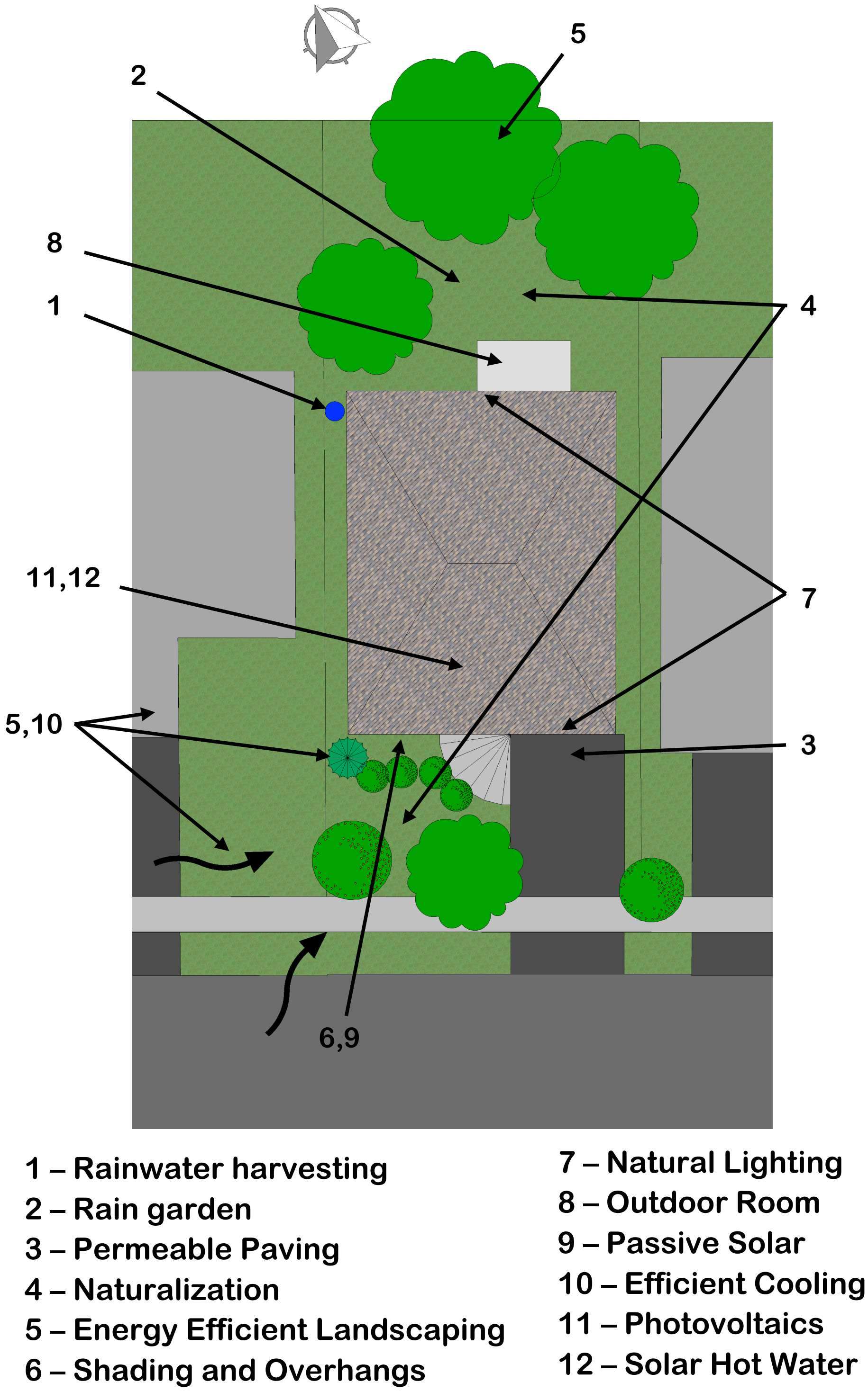


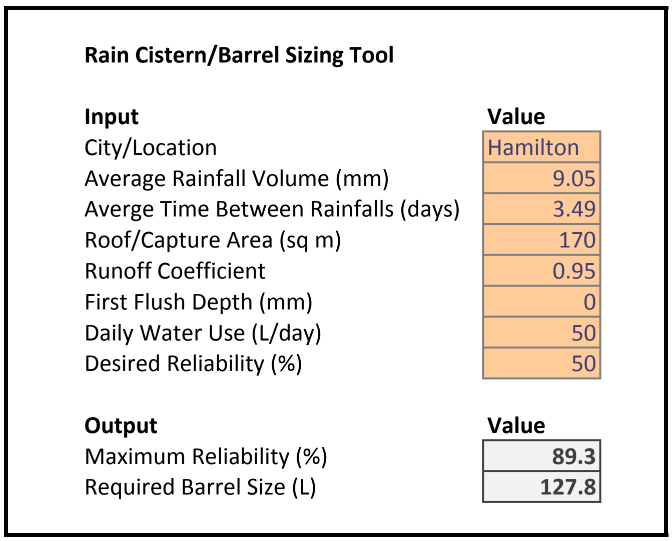
Figure 5.9: 1990's Suburban Recommendations Overview

Figure 5.10: 1990's suburban home used in application example

Rainwater Harvesting

The homeowners already use a 210L rain barrel to harvest water for their garden. The rainwater harvesting sizing tool was used to evaluate their current system. The inputs to this tool are: location, size of catchment area, daily water use, and desired reliability of the system. The closest location built into the sizing tool is Hamilton, ON, the catchment area is one quarter of the roof and measures 170 m^2, and the daily water use was estimated at 50L/day. The maximum reliability of this system is 89%. Reliability is a measure of how often there will be water in the barrel when needed and is constrained by location, roof area or catchment area, and daily water use. Figure 5.11 shows the tool for this scenario with a reliability of 50%. The tool output that for desired reliabilities of 50%, 70% and 80%, the barrel would need to be 128L, 238L, and 352L respectively.

The homeowners indicated that they would be happy with a reliability of 50%. This confirms that the homeowner already has an adequately sized system for their needs, although adding a second barrel of the same size would increase their system to 420L and the reliability to upwards of 80%. It is likely that rain barrels would not be connected to the other downspouts on the home since the existing system can provide the needed water. In this case the other downspouts should be directed to the yard to pool, to a rain garden, or to a soakaway pit. See Section 5.4.1 for an example of the application of the yard pooling sizing tool.



Rain Cistern/Barrel Sizing Tool

Input	**Value**
City/Location	Hamilton
Average Rainfall Volume (mm)	9.05
Averge Time Between Rainfalls (days)	3.49
Roof/Capture Area (sq m)	170
Runoff Coefficient	0.95
First Flush Depth (mm)	0
Daily Water Use (L/day)	50
Desired Reliability (%)	50

Output	**Value**
Maximum Reliability (%)	**89.3**
Required Barrel Size (L)	**127.8**

Figure 5.11: Screenshot of rain barrel sizing tool with user inputs and generated outputs for 90's home

Rain Gardens

Rain gardens were suggested for this home. The flat nature of the yard is well suited for rain gardens as indicated in the primer. The homeowners have an issue with excessive pooling water in a portion of their yard. Such a garden could alleviate this pooling if water were directed away from the area where pooling occurs and to a rain garden. The further reading recommended in the primer is a document that would help the homeowners design a rain garden.

Permeable Paving

The two main impervious surfaces are the driveway and roof. As mentioned, the downspouts should be directed to the lawn if not already or to a rain garden or soakaway pit. The driveway is sloped to the road and would contribute water to the storm sewer system. This could be repaved with lattice pavers that allow grass to grow in between or with gravel or any number of other permeable options discussed in the permeable paving primer. This choice would be at the homeowner's discretion.

Naturalization

The yard is predominately a grassed lawn, approximately 70% of the yard's area, with a small patio and gardens making up the rest. Thus this yard would be a good candidate for naturalization. Specially selected native flowers, bushes, and trees would reduce the amount of lawn and increase natural space. This would attract more pollinators and helpful insects that would be beneficial to the existing gardens. This is another case where the further readings would be of help to the homeowners in selecting plants and design strategies and understanding why a natural lawn is beneficial.

5.3.2. Water Use (Potable) Application

The water use category only asks one question: Are you renovating in the near future? Since running new plumbing for water recycling or treatment and can be expensive it is best combined with a planned renovation. The answer to this question was "No", there are no renovations planned. The only recommended tactic in this case is rain water harvesting. This would displace potable water used for watering outdoors. For details on rainwater harvesting as they pertain to this application, see Section 5.3.1.

5.3.3. Energy Use Application

The energy use category is much more complex than the stormwater or water use categories. There are four questions in this category, the answers for this case are as follows:

1. Q: Is your home well insulated? A: Yes
2. Q: Is there a south facing wall on your home that is exposed to the sun in the winter? A: Yes
3. Q: Do you need a new roof? A: No
4. Q: Do you have a place on your property (preferably the roof) that is south facing and exposed to the sun for most of the day all year long? A: Yes

Support was given for question 1 to evaluate insulation and for questions 2 and 4 to evaluate sun exposure. With these answers the following tactics were recommended to the homeowner for further investigation. That investigation is explained in the next sections:

a) Energy efficient landscaping
b) Shading and overhangs
c) Natural lighting
d) Outdoor room
e) Passive heating
    a. General
    b. Thermal mass
    c. Trombe wall
f) Efficient cooling (night ventilation)
g) Standalone photovoltaic
h) Solar hot water generation

Energy Efficient Landscaping

To help reduce heat loss due to wind the primer recommends a wind-block. The prevailing winds are from the west. The home is protected from these winds by the neighboring house as can be seen in Figure 5.10. The dense bushes at the base of the home on the southwest corner complement the windbreak provided by the neighboring home.

The home is shaded on the east and west by the neighbouring homes and this would reduce heat gain in the summer. The backyard has canopy coverage of approximately 75% that would cool the area around the home through evapotranspiration. The front yard is more modestly treed with about 15% canopy coverage but this acceptable since it faces south and fewer trees will increase solar gains in the winter. Overall the home already uses the existing homes and trees to effectively reduce unwanted heat losses and heat gains although increased naturalization and vegetation could enhance this effect.

Shading and Overhangs

The primer recommends using shades and overhangs on the east, south, and west windows to block the high, hot summer sun but let in the low winter sun. Due to the shade provided by the homes on the east and west, overhangs are not likely not required in these directions although shades my be useful to cut early and late day heat gains. The entire front of the home is exposed to the south and has a large amount of glazing (see Figure 5.10). Overhangs would be desirable on these windows. The windows are all 5 feet (1.5 m) tall. Using the Overhang Design Tool an overhang for these windows was sized at 1.85 feet (0.6 m). See Figure 5.4 for an example screenshot of the overhang design tool.

Natural Lighting

Most of the home's rooms have adequate day lighting due to the large number and size of windows. The homeowners have noted that this is a feature they like. If any rooms become dark enough during the day to warrant artificial lighting, a commination of light-coloured paint and furniture could reduce or eliminate this need.

Outdoor Room

Due to the neighbouring homes on the east and west, the location of an outdoor room is constrained to the front or backyard. The homeowners use a patio in the backyard and use an awning for shade from the hot sun. The front porch is protected from the wind but has sun access and could be used on cooler days. These two spaces meet the homeowners needs. For formal procedure for locating an outdoor room see Section 5.2.4 or 5.4.3.

Passive Heating

The passive solar heating primer discusses how glazing (windows, trombe walls, solar spaces, etc) can be used as supplementary heat for a home. The passive solar heating sizing and design tool can help evaluate and design passive solar techniques into the home. Currently, the home's heated floor area is 5100 square feet (474 m^2) and has 166 square feet (15 m^2) of south facing glazing. From this information the tool can evaluate the home's solar performance and then guide homeowners to increase this performance. It can be seen in Figure 5.12 that the home currently has a solar savings fraction (SSF) of 24%, but the target SSF for its location is between 44% and 68%. The SSF, a measure of the home's solar performance is calculated as shown in Equation 5.1.

$$SSF\ (\%) = \frac{\begin{pmatrix} Total\ purchased\ energy \\ of\ nonsolar\ home \end{pmatrix} - \begin{pmatrix} Total\ purchased \\ energy\ of\ solar\ home \end{pmatrix}}{\begin{pmatrix} Total\ purchased\ energy \\ of\ nonsolar\ home \end{pmatrix}}$$

Equation 5.1: SSF Calculation

The home's current SSF is not close to the target SSF. The tool can help homeowners determine the amount of glazing needed to get to the target SSF. Since the current SSF is not close to the target SSF, the proposed SSF was chosen to be at the lower end of the Target SSF, a value of 44%. As can be seen in Figure 5.12, 918 square feet (85 m^2) of glazing is needed to meet an SSF of 44%, or an additional 800 square feet (74 m^2) of glazing. This is likely going to be impossible since the front of the home does not have this much space.

In this case the homeowners would have a few options. They could build up the roofline to accommodate windows, install front doors with windows, install a sunspace or install trombe walls. Primers on sunspaces and trombe walls are included in the DSS. It may not be possible to meet the target SSF, but energy savings can still be realized without meeting the target SSF and a retrofit to add glazing without the intent of meeting the target SSF could be completed.

Sizing of Solar Glazing

Current Area of South Facing Glazing	166			
Area of Heated Floor-space	5100			
City	Toronto			
Current Ratio of Glazing to Floor Area	0.03			
Target Ratio of Glazing to Floor Area	Between:	0.18	and	0.36
Current SSF (%)	24			
Base SSF (%)	20			
Target SSF (%)	Between:	44	and	68
Proposed SFF (%)	44			
Area of Glazing needed	918			
Energy Savings (%)	20			

Figure 5.12: Screenshot of passive solar heating sizing tool with user inputs and generated outputs for 90's home

Thermal mass helps increase the efficiency of passive solar heating by acting as a temperature moderator. If the homeowners were to meet the target SSF they would need this moderation or else they would experience large temperature swings and overheating during the day. To estimate the amount of thermal mass needed a thermal mass sizing tool accompanies the passive solar sizing tool. Figure 5.13 shows the thermal mass sizing tool for this example. Thermal mass is difficult to incorporate into an existing house and it was deemed that 4-inch brick would likely be the easiest to incorporate, probably in the form of decorative indoor walls. Approximately 3000 square feet (279 m^2) of thermal mass would be needed in this case. Certainly this would prove impossible as well. In addition to the thermal mass a ventilation strategy would also be needed to move the solar heat from the front of the home to the rear. Clearly from this analysis, passive solar heating is likely going to be very difficult to incorporate into this home in any meaningful way.

Sizing of Thermal Mass

Thermal Mass Material	4" Brick
Total Glazing Area	918
Ratio of Mass Area to Glazing Area (%)	325.6
Total Area of Thermal Mass Needed	2989
No Conversion Required	N/A

Figure 5.13: Screenshot of thermal mass sizing tool with user inputs and generated outputs for 90's home

Standalone Photovoltaic

The photovoltaic tactic includes a tool for the preliminary sizing of a non-grid-tied system. This means the system does not feed back into the main grid but powers the home by itself using battery storage, known as an off-the-grid home. This requires dramatic decreases in electricity use by the homeowners. First the user inputs all of their appliances into the tool's load calculator shown in Figure 5.14. After estimating electricity usage the size of the PV system needed can be estimated. In this case the homeowners were not planning on installing a PV system and thus not replacing or reducing any of their electrical appliances. The appliances input into the calculator in Figure 5.14 are used as a sample only.

Assuming a panel output of 180W and a location of Toronto, it was calculated for the sample load shown that the homeowners would need 12 panels in June and 31 panels in December. This would meet 100% of the sample needs and take these appliances off grid as shown in Figure 5.15. Using a 24V battery system and a storage time of 3 days (the length of time the system may need to go without charging from the sun) the system would need to have a power rating of 380 amp hours and 970 amp hours for June and December, respectively. This accounts for most losses and necessary conversions from DC to AC current.

Electircal Load Calculator

AC Loads (Appliance Description)	Number of Appliances	Rated Wattage	Hours Used Per day	Watt-hours per day
Coffee-maker	1	900	0.5	450
Compter - Laptop in use	2	25	1	50
Computer - Desktop	1	250	10	2500
Dishwasher	1	1300	1	1300
Curling/Straitening Iron	1	25	0.25	6.25
Fridge - top-mount, auto defrost, 16 cu.ft, high eff.	2	54	24	2592
Furcance Fan	1	350	6	2100
Lightbulb - CFL	45	15	0.25	168.75
Microwave	1	1100	0.25	275
TV	1	100	4	400
				0
			Total AC Watt-hours per day	9842

DC Loads	Number of Appliances	Rated Wattage	Hours Used Per day	Watt-hours per day
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
				0
				0
			Total DC Watt-hours per day	0
			Total Adjusted Daily Load (DC kWh/day)	11.6

Figure 5.14: Screenshot of electrical load calculator with user inputs and generated outputs for 90's home

Panel and Battery Size Calculator

Locational Data	
Location	Toronto
December Average Radiation (kWh/m^2)	2.1
June Average Radiation (kWh/m^2)	5.4
Panel Data	
Panel Output/Rating (W)	180
Total Number of Panels Needed: December	30.6
Total Number of Panels Needed: June	11.9
Battery System Data	
Battery Voltage (V)	24
Batter Storage Time (Days)	3
Battery System Size: December(Amp Hours)	973
Battery System Size: June (Amp Hours)	378

Figure 5.15: Screenshot of panel and battery size calculator with user inputs and generated outputs for 90's home

Solar Hot Water Generation

The solar hot water primer speaks to the fact that solar hot water generation is one of the most cost-effective energy saving systems to use. The accompanying sizing tool helps owners estimate the size of the system they need to meet their needs. Figure 5.16 shows a screenshot of the tool including the inputs and outputs for the 90's home. The ambient temperatures were taken from Environment Canada. The desired temperature, hot water use, and percent of water from the collectors in July and January are recommendations from the tool's original print source (Stein & Reynolds, 2000). A single-glazed, flat plate, black chrome, selective surface collector was chosen. As shown in Figure 5.16, the homeowners would need to install 3.8m^2 of panels to meet 100% of their needs in July and 3.7m^2 of panels to meet 50% of their needs in January.

Solar Hot Water Collector Sizing Tool

Location Input	
Latitude (Degrees North)	48
Location	Toronto
Well Water Temp (C)	8.9
Ambient Air Temperature in January (C)	-5
Ambient Air Temperature in July (C)	22
Hot Water Use Input	
Desired Hot Water Temperature	40
Hot Water Use (Litres per day)	300
% Hot water from Collectors in July	100
% Hot water from Collectors in January	50
Collector Selction	
Collector Type	Single Glazed, Flat Plate, Black Chrome, Selective Surface
July Collector Efficiency	65
January Collector Efficiency	48
Collector Area Output	
Collector Area Needed For July (m^2)	3.8
Collector Area Needed for January (m^2)	3.7

Figure 5.16: Screenshot of solar hot water collector sizing tool with user inputs and generated outputs for 90's home

5.3.4. 90's Suburban Home Concluding Remarks

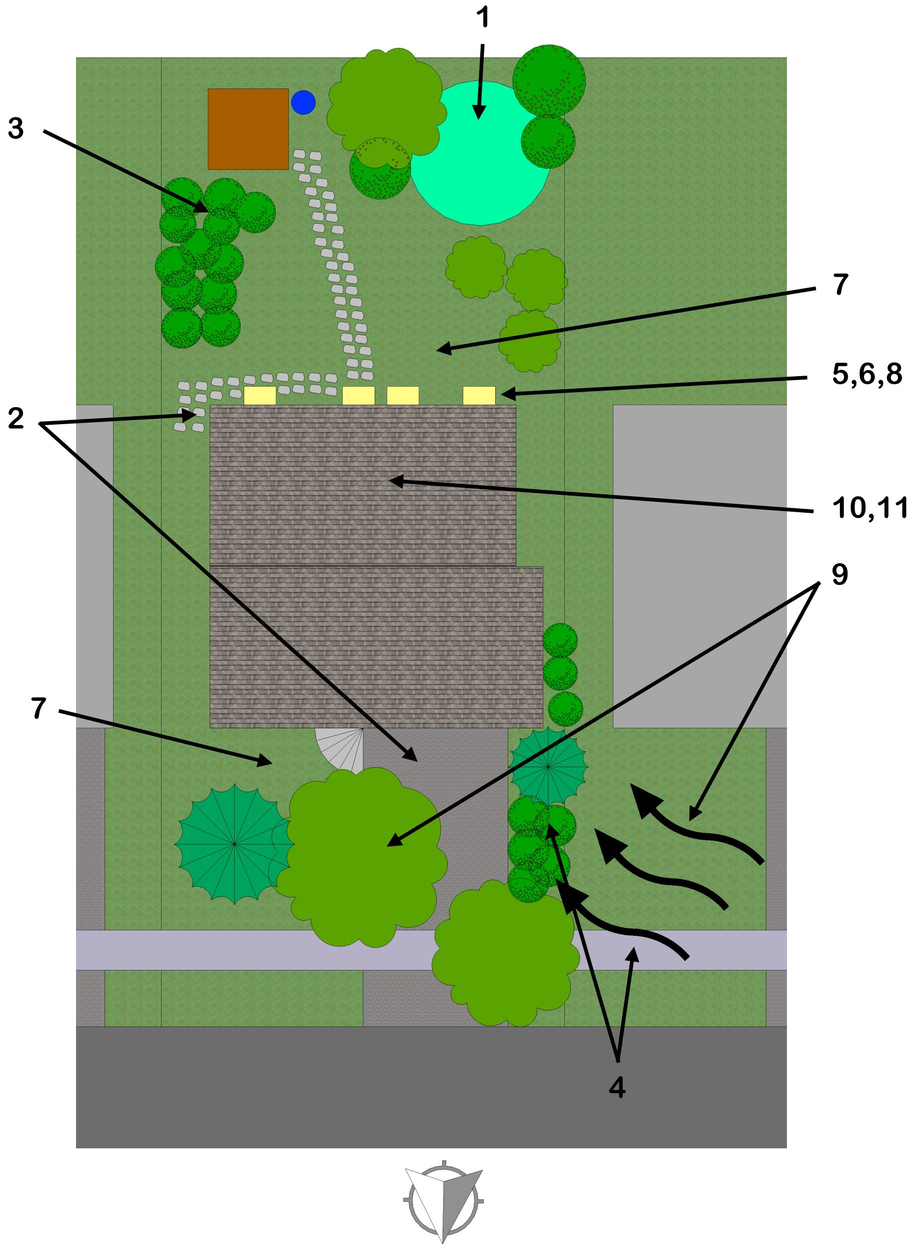
In this example, the home was similar to the post-war suburban home in terms of stormwater, water use, and many of the initial energy use recommendations. The differences were in some of the larger energy use reduction recommendations. Since this home was better insulated, passive solar became an option, but the home ended up being poorly suited to take advantage due to its size. For PV to become feasible, energy use would need to be drastically reduced. The solar hot water option seemed feasible but would require more panel area than the post-war home due to the larger number of occupants.

5.4. TWO FAMILY CONVERSION APPLICATION

Recall that the two family conversion takes a 4 bedroom, 3 ½ bathroom, 2,808 square foot home and converts it into two 3 bedroom, 1 ½ bathroom dwellings. Both units were designed to be large enough for families with children. See 4.1.2for details on the conversion and layout of the home. For an overview of the recommendations generated by the Environmental Impact Module see Figure 5.17. For this application a typical scenario for the home's location and site conditions must be assumed. The following has been assumed:

- The home is located in Winnipeg, MB in a suburban setting
- The home faces north and the back of the home has an unobstructed southern exposure
- There are homes on the east and west sides
- Recently built within the last 5 years and was recently converted to the two family set-up
- Excellent insulation
- The lawn is xeriscaped
- The driveway is not paved
- The backyard slopes to a swale at the southern edge of the property that drains to a storm sewer system

From these assumptions, the developed DSS can be applied.



1 – Yard Pond
2 – Permeable Paving
3 – Naturalization
4 – Energy Efficient Landscaping
5 – Shading and Overhangs
6 – Natural Lighting
7 – Outdoor Rooms
8 – Passive Heating
9 – Efficeint Cooling
10 – Photovoltaic
11 – Solar Hot Water

Figure 5.17: Two-Family Conversion Recommendations Overview

5.4.1. Stormwater Management Application

The stormwater management section asks only one question: Do you use water outdoors (washing, watering, etc.) AND/OR do you (or would you) garden? The answer was "No", the homeowners have a xeriscaped lawn that is vey low maintenance and only requires periodic pruning and watering which they do with a rain barrel attached to their shed. Their xeriscaped lawn was designed to be very low maintenance (equivalent in effort and time to cutting a lawn) since the owners do not enjoy gardening. With this information the DSS suggests the homeowner investigate yard ponding, soakaway pits, permeable paving and yard naturalization.

Rainwater Harvesting

The tool does not recommend rainwater harvesting although the homeowners use a small barrel for the few watering needs that they have. It is attached to a large storage shed in their yard and is sufficient.

Yard Ponding and Soakaway Pits

After reading the primers and noting that yard ponding and soakaway pits are mutually exclusive, the homeowners decide that yard ponding would be a good choice. Using the yard ponding evaluation tool the homeowners can evaluate the suitability of the yard for ponding. Figure 5.19 shows the site evaluation form used to determine if yard ponding is feasible. It uses a point system based on site conditions. Depending on the final tally of points the site is scored as 'Very good' (greater than 30 points), 'OK' (20 to 30 points), or 'Poor' (less than 20 points) in terms of suitability. The drainage area (the roof) and the area for ponding (the yard), is entered, as shown in Figure 5.19. Then various site conditions are chosen from a drop-down menu. The home's site scored 28 points which rates it as 'OK' in terms of suitability. After determining that the site is suitable the homeowners can now estimate a pond size using the yard ponding sizing tool.

Figure 5.18 shows the sizing tool used to estimate the size of the yard pond needed. The area to be drained is the same as in the site evaluation form. The reliability is 85%. This means that the pond will accommodate all the rainfall volume 85% of the time. The runoff coefficient is estimated at 0.8 or 80% since some water will not make it to the yard pond. Finally, a pond depth of 70mm was chosen. This is a new home and the yard slopes to the back to a swale. Given the grade, a 70mm deep pond is feasible. Note that this "pond" will only briefly contain water after a rain. It can be seen in Figure 5.18 that if the pond were square it would need to measure 4.9m by 4.9m for an area of 24m^2, well within the available 75m^2 surface area available. The only real work that the homeowners need to do is to build a small berm at the rear of their yard to capture the water before it goes into the swale and subsequently the storm sewer system. Care should be taken to make the berm low enough that in overflow situations the water breaches the berm before reaching the home.

Yard Ponding Sizing Tool

Input	
City	Winnipeg
Average Rainfall Depth (mm)	7.9
Area to be drained (sqaure meters)	140
Pond Reliability (%)	85
Runoff Coefficeint (0-1)	0.8
Pond Depth (mm)	70
Output	
Pond Volume (square meters)	1.68
If the area was squre the sides would be (m)	**4.90**

Figure 5.18: Screenshot of yard pond sizing tool with user inputs and generated outputs for two family conversion

Site Evaluation Form

		Input	Points
1 Area drained and area available for infiltration			
	What is the area of the impervious surface that will be drained (square meters)?	140	
	What surface area is available to place the pit (square meters)?	75	
			5
2 Surface soil type			
	What is the type of surface soil (first 5-10 cm)?	Normal humus soil	
			5
3 Subsurface soil type			
	What type of soil is under the surface soil (10-100 below surface)?	Coarser than the surface soil (if not, select the type below)	
			5
4 Slope Site			
	How steep is the groud at the poential site?	Moderately Sloped	
			3
5 Vegitation Cover			
	What type of vegitation cover is present on the potential site?	Healthy - natural vegitation, naturalized lawn	
			5
6 Degree of traffic on infiltration surface			
	How much traffic would the surface see?	Little foot traffic - garden, ornamental lawn	
			5
Refer to **Step Two** intructions to the left for interpretation of points		**Total**	28

Figure 5.19: Screenshot of yard pond site evaluation tool with user inputs and generated outputs for two family conversion

Permeable Paving

The home is relatively new and still has a gravel driveway and there is a small deck in the back yard. Thus the only impervious surface is the roof and a yard pond has been sized to accommodate that runoff. The homeowners now must consider options for finishing the driveway. Leaving it as gravel is less than ideal since the gravel can wash away and potentially end up as excess sediment in local water bodies. As shown in the permeable paving primer in Appendix E, there are many options to choose from to finish the driveway with a permeable material.

Yard Naturalization

The yard is already naturalized since it is xeriscaped. Further research could be done to select plants that attract certain types of pollinators desired by the owners (butterflies, humming birds, etc).

5.4.2. Water Use (Potable) Application

The water use category only asks one question: Are you renovating in the near future? Since running new plumbing for water recycling or treatment and can be expensive it is best combined with a planned renovation. The answer to this question was "No", since the home was recently converted and still meets the needs of the homeowners. The recommended tactic is then rainwater harvesting to eliminate the use of potable water outdoors, but since the lawn is xeriscaped, no potable water is used outdoors. Thus there are no tactics in this category that are applicable.

5.4.3. Energy Use Application

The energy use category is much more complex than the stormwater or water use categories. There are four questions in this category, the answers for this case are as follows:

1. Q: Is your home well insulated? A: Yes
2. Q: Is there a south facing wall on your home that is exposed to the sun in the winter? A: Yes
3. Q: Do you need a new roof? A: No
4. Q: Do you have a place on your property (preferably the roof) that is south facing and exposed to the sun for most of the day all year long? A: Yes

Support was given for question 1 to evaluate insulated levels and for questions 2 and 4 to evaluate sun exposure. With these answers the following tactics were recommended to the homeowner for further investigation. That investigation is explained in the next sections:

a) Energy efficient landscaping
b) Shading and overhangs
c) Natural lighting
d) Outdoor room
e) Passive heating
    a. General
    b. Thermal mass
    c. Trombe wall
f) Efficient cooling (night ventilation)

g) Standalone photovoltaic
h) Solar hot water generation

Energy Efficient Landscaping

The prevailing winds in Winnipeg are from the northwest. According to the primer the homeowners should plant dense shrubs around the north and west of the home. Some larger evergreens such as eastern white cedars or white spruces (both native to the area) would be an asset on the front yard that faces north. The home is shielded on the east and west by neighboring homes.

In terms of reducing heat gains, again the home is shaded on the east and west by neighbouring homes. The trees planted in the front yard should have a canopy that covers as much of the yard as possible and should shade the driveway and rear of the roof. The xeriscaped lawn will also help reduce local temperatures but for solar access reasons, only small shrubs should be planted in the back yard that faces south.

Shading and Overhangs

Shading the driveway and roof was addressed in the energy efficient landscaping evaluation above, and the east and west windows will be shaded by the neighbouring homes. The south facing windows could have overhangs to help reduce unwanted summer heat gains. Noting that Winnipeg is at 49^{o} latitude and assuming all the windows on the south of the home are 5 feet (1.5 m) tall and shading is desired from May to July, overhangs can be sized at 2.3 feet (0.7 m). Figure 5.4 shows this tool used in another example.

Natural Lighting

It appears that the living spaces on the south side of the home would receive ample natural light. The rooms at the front of the home may suffer from a lack of natural light depending on the vegetation used for shading. These rooms should be painted a light colour and furnished with light-coloured furnishings to increase the light levels. If light levels are still too low then solar tubes can be installed to let natural light into these rooms.

Outdoor Room

These homes both need access to the outdoors. Using the design table provided in the outdoor room placement tool, locations for outdoor spaces can be recommended. The prevailing wind (from the west) is perpendicular to the sun (from the south). The summer is temperate and humid while the winter is cold. Using this information and the design table, the outdoor space in the summer should be shaded from the southern sun but have access to the wind. This would likely be the front yard that faces north and is shaded by trees and the home, or less optimally a sun screen could be used in the backyard for shading. In the cooler months in Spring and Fall the backyard would be the best place for an outdoor room since it would be sunny and protected from the wind.

Passive Heating

The passive solar heating primer discusses how glazing (windows, trombe walls, solar spaces, etc) can be used as supplementary heat for a home. The passive solar heating sizing and design tool can help evaluate and design passive solar into the home. The home has a heated floor area of 4200 square feet (390 m^2) (both units combined) and 160 square feet (15 m^2) of south facing glazing. From this information the tool can evaluate the home's solar performance and then guide homeowners to increasing this performance. Using the same tool as shown in Figure 5.12, the home was calculated to have a SSF of 37% but the target SSF for Winnipeg is between 54 to 74. The SSF, a measure of the home's solar performance is calculated using Equation 5.1.

The home's current SSF is not close to the target SSF. The tool can help homeowners determine the amount of glazing needed to get to the target SSF. The proposed SSF was chosen to be the lower end of the Target SSF, 54%. It was determined using the sizing tool that 1050 square feet (98 m^2) of glazing is needed to achieve an SSF of 54%, or an additional 890 square feet (83 m^2) of glazing. This is likely going to be difficult for space reasons.

In this case the homeowners would have a few options. They could build up the roofline to accommodate windows, install more windows or install a sunspace or install trombe walls, along the south wall. As can be seen in the layout of the home in Figure 4.3 there is space along the rear walls for more windows. If 85% of the rear wall were turned into windows the home would have a total of 425 square feet (39 m^2) of windows and a SSF of 42%, a substantial improvement. Assuming this was undertaken and that no windows were built into the roofline the home would need an air movement system to move the warm air form the rear of the home to the front of the home. Since the home's SSF does not meet the target SSF it would not need to incorporate thermal mass. It may not be possible to meet the target SSF but a home does not need to meet the target SSF to realize energy savings and it would be acceptable to commence a retrofit and add glazing without the intent of meeting the target SSF.

Efficient Cooling

Using the same cooling strategy selection tool as shown in Figure 5.5, it was determined that natural, fan, or stack cooling would be sufficient to cool this home. Using the same heat gain calculation tool as shown in Figure 5.6, it was determined that the estimated average daily heat gain for this home is 230 MJ. This assumes all windows are 5 feet (1.5 m) tall, 7 people live in the home between the two units and there are 45 light bulbs in the home.

If the homes use casement windows on the north side that open to catch the wind northwest winds, they can act very effectively as inlets for the wind. Using an estimated 5.5 square meters of inlet windows, an average local wind speed of 18.4 km/h, an indoor temperature of 26^{o}C (average daily high in July) and an outdoor temperature of 13^{o}C (average daily low in July) all from

Environment Canada, the flush time can be estimated at 35 minutes. The lower unit may have some issues since there is only one north-facing window. Fans placed in the windows can help facilitate air movement. The upper unit should not have problems due to the large number of north-facing windows. Care must be taken to ensure there is an outlet window and that the air can flow unobstructed (no closed doors) from the inlet to the outlet.

Standalone Photovoltaic

The photovoltaic tactic includes a tool for the preliminary sizing of a non-grid-tied system. This means the system does not feed back into the main grid but powers the home by itself using battery storage. This requires dramatic decreases in energy uses by the homeowners. A sample of common household appliances were input into the load calculator shown in Figure 5.20 and represent the majority of the electrical load for a home that needs to conserve energy. After the energy load has been estimated the size of the PV system can be estimated.

From the electrical usage estimated with the tool shown in Figure 5.20, the number of panels required can be estimated. Assuming a panel output of 180W, it was calculated for the sample load shown the homeowners would need 7 panels in June and 13 panels in December as shown in Figure 5.21. This would meet 100% of the home's needs. Using a 24V battery system and storage time of 3 days (the length of time the system may need to go without charging from the sun) the system would need to have a power rating of 220 amp hours and 410 amp hours for June and December respectively. This accounts for most losses and necessary conversions from DC to AC current.

Solar Hot Water Generation

The solar hot water primer speaks to the fact that solar hot water generation is one of the most cost effective energy saving systems to use. The accompanying sizing tool helps homeowners estimate the size of the system they need to meet their needs. Figure 5.22 shows a screenshot of the tool including the input and outputs for the two family conversion. The ambient temperatures were taken from Environment Canada. The desired temperature, hot water use, and percent of water from the collectors in July and January are recommendations from the tool's original print source (Stein & Reynolds, 2000). Note they are the same values as those used in the post-war home example. A different collector was chosen this time; the single-glazed, evaporative tube, concentric selective absorber. As shown in Figure 5.22, the homeowners would need to install 5.3m^2 of panels to meet 100% of their needs in July and 4.2m^2 of panels to meet 50% of their needs in January.

Electircal Load Calculator

AC Loads (Appliance Description)	Number of Appliances	Rated Wattage	Hours Used Per day	Watt-hours per day
Compter - Laptop in use	2	25	4	200
Fridge - top-mount, auto defrost, 16 cu.ft, high eff.	2	54	8	864
Front Load Washer	1	160	0.4	64
Furcance Fan	1	350	6	2100
Microwave	2	1100	0.25	550
Radio	2	5	4	40
Vacuum	2	500	0.15	150
DVD	2	30	0.65	39
	1	#N/A		#N/A
	1	#N/A		#N/A
				0
			Total AC Watt-hours per day	4007

DC Loads	Number of Appliances	Rated Wattage	Hours Used Per day	Watt-hours per day
Coffee-maker	2	140	0.5	140
Hair Dryer	2	400	0.15	120
Lighting - CFL	45	15	2	1350
TV	2	60	3	360
		#N/A		#N/A
		#N/A		#N/A
		#N/A		#N/A
				0
			Total DC Watt-hours per day	1970
			Total Adjusted Daily Load (DC kWh/day)	6.7

Figure 5.20: Screenshot of electrical load calculator with user inputs and generated outputs for two family conversion

Panel and Battery Size Calculator

Locational Data	
Location	Winnipeg
December Average Radiation (kWh/m^2)	2.9
June Average Radiation (kWh/m^2)	5.4
Panel Data	
Panel Output/Rating (W)	180
Total Number of Panels Needed: December	12.8
Total Number of Panels Needed: June	6.9
Battery System Data	
Battery Voltage (V)	24
Batter Storage Time (Days)	3
Battery System Size: December(Amp Hours)	407
Battery System Size: June (Amp Hours)	218

Figure 5.21: Screenshot of panel and battery size calculator with user inputs and generated outputs for two family conversion

Solar Hot Water Collector Sizing Tool

Location Input	
Latitude (Degrees North)	48
Location	Winnipeg
Well Water Temp (C)	6.7
Ambient Air Temperature in January (C)	-17.8
Ambient Air Temperature in July (C)	19.5
Hot Water Use Input	
Desired Hot Water Temperature	40
Hot Water Use (Litres per day)	300
% Hot water from Collectors in July	100
% Hot water from Collectors in January	50
Collector Selction	
Collector Type	Single Glazed, Evaporative Tube, Concentric selective absorber
July Collector Efficiency	48
January Collector Efficiency	48
Collector Area Output	
Collector Area Needed For July (m^2)	5.3
Collector Area Needed for January (m^2)	4.2

Figure 5.22: Screenshot of solar hot water collector sizing tool with user inputs and generated outputs for two family conversion

5.4.4. Two Family Conversion Concluding Remarks

This application example shows how the yard ponding tool can help homeowners evaluate their yard for ponding and then size an appropriate area. The soakaway pit uses a very similar approach. Also observed in this application was that the home's location made natural ventilation very effective in the summer. A combination of cold winters and the small area of south-facing glazing made passive solar difficult to achieve on a meaningful scale. This was similar to the 90's suburban home and is due to the very large floor areas. The PV and solar outcomes were similar to the 90's conversion as well. They seemed feasible in terms of size since the home's south facing roof area can be estimated at about $80m^2$.

5.5. Reducing the Environmental Impact Module Application Conclusions

Using these three typical suburban homes, the Reducing the Home's Environmental Impact Module was applied. It was seen that many of the tactics would require further homeowner research and evaluation but the primers provide valuable guidance. Many of the tactics were already achieved either due to chance or homeowner action, demonstrating that many of the tactics are easy to implement. In all the homes evaluated it was shown that artificial cooling (air-conditioning) is not required in these climates when the home is well designed and uses the tactics recommended. The large floor area relative to the south facing glazing made the two newer suburban homes difficult to retrofit. However, it was shown that when homeowners reduce their electricity load, photovoltaics become a viable option for generating electricity, before any financial considerations. The same was true for solar hot water generation. Overall the tool was successfully applied and it was shown to be potentially useful in terms of preliminary evaluations, evaluating existing site conditions, and estimating the size or design for tactics that would reduce the home's environmental impact.

5.6. DSS APPLICATION CONCLUSIONS

In applying the module to various locations and homes, the versatility of the developed DSS became evident. This chapter illustrated how it can be applied as both a design and evaluation tool across North America. The next chapter, Chapter 6, concludes the thesis by summarizing major outcomes. It also draws various conclusions based on the literature review and the development and application of the DSS and makes recommendations for further research.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. SUMMARY OF DSS DEVELOPMENT

The literature review in Chapter 2 revealed a North American suburban landscape slowly evolving and changing from its traditional form. Some of these changes have already taken place while others have yet to occur. Many of these changes are due to shifting demographics, shifting economies, and an uncertain energy and climate future. This review demonstrated the need for communities, especially suburban ones, to adapt and become more resilient. This thesis developed a prototype DSS to address this need for increased resilience. The DSS's goal is to empower North American suburban homeowners (and their contractors) to make informed choices about their home to increase their individual and community resilience. Three different needs were addressed in the DSS through three constituent modules. They were the Dividing Suburban Homes Module, the Sustainable Additions Module, and the Reducing the Home's Environmental Impact Module.

To address the need for a diversity of housing types, dividing suburban homes into multiple units was proposed to increase density and diversity in the suburban hosing stock. To help homeowners accomplish this, spatial guidelines were developed to inform homeowners how a divided home should use space. These guidelines were then applied to three representative suburban homes showing the floor plans before and after a division had occurred. A variety of outcomes were explored as well as the associated costs. Also included was information on barriers to dividing homes and certain architectural features that were a hindrance.

When dividing a home the need for an addition may occur. The DSS addressed this need by recommending resilient, earth-based building materials, specifically straw bale, rammed earth, and adobe. The DSS recommended these materials based on local climate conditions. Photos and resources to learn more about these methods were also included.

Finally, the DSS addressed the need for reducing the environmental impact of existing suburban homes. This module had homeowners answer questions about their home and their future plans, and then recommended tactics most relevant to their situation that would reduce the environmental impact of their home. The tactics moved beyond cosmetic solutions to address the structure of the home and the management of the property. It addressed in depth three aspects of the home's environmental impact: energy use, stormwater management, and indoor potable water use. Included in the Environmental Impact Module were three main components: information sheets called primers, tools to help design the various tactics, and references for further reading.

These three aspects of suburban retrofitting, dividing homes, selecting resilient building materials, and reducing the environmental impact of the home, can help to increase the resilience of suburban homes, and thus the greater community. The three modules were loosely integrated together to allow homeowners to explore all three modules but could also function on their own increasing the versatility of the DSS.

6.2. CONCLUSIONS

6.2.1. Suburban Level

There is a non-consensus in the literature about the effect contemporary suburban form has on community. It seems as if there is a decline in civility and community in cities that some writers attribute to the suburban form itself while others argue it is a general affliction of the city and modern society. However, more resilient communities can be realized by suburban retrofitting. Local infrastructure, both social and physical is important to maintain and retrofitting can certainly address the related physical attributes. Overall resiliency does not seem to be an explicit feature of new suburbs or a subject of wide discussion in the property development community.

New suburban developments and existing suburbs will not meet the needs of North America's ageing society in their present form. The housing market is currently saturated with single-family homes, and as a result there is a rising demand for new types of dwellings. Due in part to this saturation, there is widespread suburban decline that will require new models for revitalization. Two other possible threats that the suburbs are not equipped to handle are climate change or higher energy prices. Both should be addressed in new models for retrofitting or adaptation.

Bylaws are barriers to proactive retrofitting due to restrictions on water use, energy use, and space use. Homes are built to use large amounts of fossil fuels, which is not resilient, dictated in part by municipal bylaws. Convincing people to change their lifestyle was not addressed in this DSS but will also be a large barrier to retrofitting. Also not addressed in the DSS development but explored in the literature was that the pricing structure of suburbs. This needs to be changed to make retrofits more appealing.

Retrofitting at the large scale is in the early stages of development, although revitalization and infill developments experiences could be borrowed from and built upon for retrofitting purposes. At the house-level, retrofitting tools exist, albeit generally in isolation of one another and not identified explicitly as retrofitting tools. Retrofitting is needed at both scales since leveling the suburbs and building new developments would be prohibitively wasteful and expensive.

6.2.2. Dividing Suburban Homes

Resistance to change in the suburbs, especially proactive change before decline occurs, is a barrier that will need to be addressed. However, divisions are not a turnoff for all people as many deem higher-density housing adaptations such as row-houses, town houses and duplexes appealing. Further bolstering the case for division is the fact that dividing homes does not appear to be prohibitively expensive, on the contrary a conversion can be paid off in several years at modest rental rates. Dividing homes can also increase density and possibly meet the critical density needed to create walkable communities, a must for resiliency.

Dividing homes can create inexpensive dwellings and foster pride of ownership if bylaws are changed to allow for ownership of such units. Operating costs are used more effectively in a divided home since resources are more easily shared such as the washer/dryer, lawnmower, power tools, and utility costs.

Suburban homes are not designed with future adaptation or division in mind. There are however common features in suburban homes, such as master ensuites and roughed-in plumbing in the basement that can lend themselves to division. As well, suburban homes often have enough floor space to accommodate two modestly-sized units but second living spaces in the individual units can be difficult to create without significant alterations to the existing floor plan.

Dividing homes can meet the needs of the elderly, allowing them to remain in the community. This is positive for both the person and the community. Homes should promote independence for seniors and not segregation from the community or larger city. Garden suites compliment home division in creating diversity and density in the suburbs and are an excellent way, if bylaws are changed, to address the needs of an ageing population.

6.2.3. Additions and Alternative Building Methods

Other materials besides wood/stick-frame construction are suitable building materials but are not widely used despite their benefits. More widespread use of alternative materials, such as those recommended in the prototype DSS, would be beneficial as examples begin to show how these methods are used, how they look, and how they can benefit the homeowner, community, and environment.

6.2.4. Reducing the Environmental Impact of Suburban Homes

Design that reduces the energy use of homes must to be implemented in new and existing homes. Past and current suburban development models do not take into account site conditions and how they impact fossil fuel energy demand.

Aspects such as solar or wind access are not often considered, resulting in homes that are poorly suited for certain retrofits.

The application of this module to the three suburban homes shows that many tactics in the Environmental Impact Reduction module are easily achievable. In fact, many homes already employed some of the recommendations. Anticipating future opportunities becomes key for adopting some of these tactics such as incorporating energy-efficient landscaping practices into future landscaping plans. In cases where certain tactics are already being used, the module becomes a method for verification as was shown in several places in the application examples. Much of this module is qualitative or designed at a coarse scale and challenging to specifically measure without complex computer models.

Lot-level stormwater management appears to hold great promise for reducing impacts on ageing storm sewers and the environmental impact of poorly designed stormwater systems. The very nature of lot-level stormwater management means landowners are well positioned to adopt these tactics and have significant positive impacts.

While newer suburban homes seemed more difficult to retrofit due to the large amount of energy needed to operate such sizeable homes, they may have better solar access than older suburbs since trees in new suburbs are often smaller and do not pose shading issues. Given that trees and other shading strategies can extend shadows beyond property lines, it is important to make sure that when retrofitting one home, it does not take away opportunities for retrofitting another.

Air conditioning is overused in North America, due to inefficient home designs that neglect the natural climate and sun, and due to poor knowledge of alternatives by homeowners. It is important to note that most of Canada and many regions in the United States do not require a traditional mechanical air conditioner to maintain comfortable temperatures if the home is well-designed. Resilient solutions are often simple solutions that eliminate the need for complex mechanical systems.

6.2.5. DSS Development

Additional application examples make the DSS more understandable to users. These repeated applications also revealed trends in home design and opportunities and barriers to application of the DSS that are potentially useful to end users.

There does not seem to be a straightforward way to automate the retrofitting of a home due to the variability across home designs and site-specific constraints. It seems as if most DSSs of this type will require significant user input and/or external decision-making. The developed prototype DSS was built so that contractors across North America could use this DSS as a feasibility tool to estimate designs and costs of renovations. The tradeoff for this widespread applicability is that it may be too coarse for design beyond feasibility and estimation purposes. Actual performance could differ greatly, although this can also be the case in buildings designed with complex and comprehensive computer models.

The developed prototype DSS is useful to individual homeowners and contractors but someone who has broad knowledge of all the aspects will be able to integrate the results to a higher degree better. They will be able to anticipate opportunities and be able to link the three modules together mentally beyond the explicit links built into the DSS. Regardless of prior knowledge users should be prepared to spend time with the DSS and gather the appropriate information. This DSS requires further reading and investigation to be useful and cannot be completed without the appropriate time allocation.

6.3. RECOMMENDATIONS FOR NEXT STEPS

The proposed recommendations and next steps fall into one of three categories. First, there are short-term steps that could be completed to enhance the DSS. Generally these steps would simply require more time or very small amounts of money to complete. They would not change the essence of the DSS but rather improve on what exists, taking it from a prototype to a professional software package. Second, there are medium-term steps that would enhance the DSS by refining it to a level where it could be used for detailed design, catered to specific cases. This would be proven through modeling and rigorous measurement. These steps would change the essence of the DSS and likely require substantial funding. Finally there are big-picture or long-term next steps. These move beyond the DSS itself to the context of suburban retrofitting. They would be separate research endeavors on their own.

6.3.1. Short Term

Potential users have not tested the prototype DSS outside the developer. Thus there is some uncertainty regarding its ease of use. To be effective the DSS should be easily understandable and accessible to users. Steps have been taken to make the DSS easy to use and understand but further work may be needed. The DSS should be tested by multiple users to solicit feedback and improve aspects of the DSS. This will likely require the development a better graphic user interface, improvement of links between various aspects of the DSS, and changing certain language for easier comprehension. There also may be aspects of the DSS that are not useful or generally inapplicable that could be removed while other aspects omitted from the DSS may be deemed useful and included.

For the Sustainable Additions Module developing a soil map for soils that are appropriate for rammed earth and adobe would be useful. This could better refine the locations in North America suitable for rammed earth and adobe or confirm that appropriate soils are found throughout all regions of North America. This data is likely available through Natural Resources Canada or the US Geological Survey.

The Dividing Homes Module has a useful list of architectural guidelines for space use. A sister list of guidelines for structural design based off the Building Code of Canada and United States would be a useful addition. This could help homeowners better predict cost and feasibility of certain divisions as well as make them aware of some of the structural and safety issues that are needed in an extensive renovation. This would also better prepare them when communicating with contractors.

Finally, a detailed costing tool for all aspects of the DSS could be developed. This would allow homeowners to better estimate the costs of various improvements, additions, or divisions. Completing this may include getting multiple quotes for contractors on multiple aspects of the DSS and providing representative examples of changes to the home and their cost. It could also consist of a tool that requires homeowners to input components of the work to be completed and the associated costs could be calculated.

6.3.2. Medium Term

The DSS has been theoretically applied to several homes but physical application and measurement over time could verify its accuracy. Especially important would be the construction of a straw bale and earth-based addition to a suburban home. This would demonstrate both performance and appearance. Physical application of the Environmental Impact Module could lead to improvements to help refine the level of design from coarse to fine. In addition to physical application, professional consultation could be sought. For example the stormwater management and energy design tools could be applied to a home while a professional designer applies computer models. The results could be compared to evaluate the accuracy and precision of the DSS.

After this testing the DSS could be possibly split into a two-tier system. One level would be a feasibility and cost estimation tool and the second level would be a detailed design tool. After confirming the general design and estimation, the second level of the tool could be applied for detailed design. This type of DSS could be very powerful for contractors and drafters, especially if there is sufficient verification through the modeling and application discussed above. These professionals could then feel confident in using the DSS to easily design and model potential renovations and their associated costs.

A potentially useful DSS for municipalities, homeowners, homebuyers and real-estate agents would be a resiliency mapping tool or resiliency rating tool that could be applied to a suburb. Users could use this DSS to determine the resiliency of a suburb against multiple criteria, such as walkability and local infrastructure. This could be used by municipalities when planning to improve the resiliency of a suburb, by homeowners to evaluate their vulnerability to adverse change (climate change, fuel cost increases), and by potential homebuyers to make choices about where they may want to move. The DSS could range from simple, such as a checklist, to very complex, such as a computer model.

Finally, retrofitting models at the large scale are currently in the development process. House-level tools for retrofitting already exist, but need to be brought together much like this DSS. Since the larger suburban retrofits and home-scale retrofits are intimately related, the two should be integrated together. At this stage it is uncertain what this integration would look like but it could avoid the two working at cross-purposes or doing the same work twice, harmonizing the two for maximum positive impact.

6.3.3. Long Term and Big Picture

After the DSS has been refined to a level where it can be used for detailed design, it could be applied to an entire neighbourhood to assess the reduction of overall impacts and the increase in overall density. This application would involve the physical retrofitting of the homes and would need a detailed assessment and plan for the community to determine which homes to retrofit. It would likely be beneficial to have this coincide with a larger-scale retrofit to get maximum impact. The resiliency-mapping tool or resiliency-rating tool suggested previously could be used to evaluate resiliency before and after.

Regardless of the retrofitting method, an inventory of suburbs ripe for retrofitting should be developed. This could be done in a systematic way from region to region and possibly use the resiliency-rating tool previously suggested. This inventory could take into consideration criteria such as social setting and how the community would react to a proposed retrofit, the state of repair of the homes and infrastructure, as well as other criteria. This inventory may contain a rating system to assess the state of decline or blight or a risk rating to assess vulnerability to blight.

More flexibility in bylaws is needed. They currently restrict land use and hinder the development of diverse dwelling types in the suburbs. They pose barriers for resilient community infrastructure such as community-based water reuse and treatment. The development of bylaws to allow for these practices is needed, while ensuring safety and the quality of life of community members.

To advance rammed earth, adobe, and straw bale construction, a building code specific to these materials may help, similar to the one that exists for stick-frame construction. There is sufficient research available to begin to develop these codes, although more research would be needed specifically to determine straw bale's appropriateness in a hot-humid climate. Other research would likely be needed as well, although at this stage it would be to further refine the science of building with these materials, not to develop the fundamentals needed for a building code.

The green building rating systems discussed in the literature review are good for guiding new building as well as large renovations. However, it would be helpful to develop a green building rating system that provides homeowners with a way to meet the requirements in steps as renovations are completed. Many people build or improve parts of their home incrementally as finances allow. Creating a rating system (or creating a new stream for an existing rating system) that allowed homeowners to incrementally build up to the final designation and tracking their progress along the way would better reflect how homeowners renovate and retrofit their homes.

6.4. Final Remarks

There is clearly a need for change in the suburbs. Command and control organizations such as governments can create plans for regional change in retrofitting, however homeowners are in a unique position to increase the resiliency of their homes and suburbs. They can meet many requirements for resiliency at the home-level that then translate into resiliency at the suburb or community level. The developed prototype DSS clearly lays out a system to assist homeowners to take advantage of this position. It also anticipates the future needs in the suburbs to address these specifically. This prototype DSS can now be adapted or used as a model for further work that can increase the resiliency of the suburbs. The opportunities and tools needed are many and there are multiple avenues waiting for further exploration to create resilient suburban communities.

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APPENDIX

APPENDIX TABLE OF CONTENTS

APPENDIX A – THE SLOW HOME TEST

THE SLOW HOME TEST

Evaluate the Quality of the Design Underlying Any House

	The 12 Steps to a Slow Home	Yes	No
The House in the World	**1 Location** A Slow Home is located in a walkable neighborhood that is in proximity to work, shopping, and amenities in order to minimize the use of a car.	3	0
	2 Size A Slow Home is correctly sized to efficiently fit the needs of its residents in order to reduce unnecessary energy consumption and greenhouse gas emissions.	3	0
	3 Orientation A Slow Home is properly oriented to the sun, prevailing winds, and immediate surroundings in order to facilitate natural heating and cooling.	2	0
	4 Stewardship A Slow Home conserves land and water for future generations, reinforces smart, compact city growth patterns, and makes a positive contribution to the community.	2	0
The House as a Whole	**5 Entry** The front and back entries in a Slow Home are good-sized spaces of transition with adequate storage and, if possible, room for a bench.	1	0
	6 Living All indoor and outdoor living spaces in a Slow Home have good daylight, a natural focal point, and can accommodate a wide variety of uses without wasted space.	1	0
	7 Dining The dining area in a Slow Home is a day-lit space located close to the kitchen and can properly fit a table without any circulation conflicts.	1	0
	8 Kitchen The kitchen in a Slow Home is located outside of the main circulation route and has an efficient work triangle, continuous counter surfaces, and sufficient storage.	1	0
	9 Bedrooms All bedrooms in a Slow Home have good daylight, sufficient storage, a logical place for the bed, and enough room for circulation.	1	0
	10 Bathrooms All bathrooms in a Slow Home have private but accessible locations, are well-organized, modestly sized, and have sufficient counter space and storage.	1	0
	11 Utility A Slow Home has utility spaces for parking, laundry, mechanical equipment, and storage that are unobtrusively located, highly functional, and do not conflict with other uses.	1	0
	12 Organization A Slow Home is efficiently organized with like rooms grouped together and clear unobstructed circulation.	3	0

Minimum Design Quality Threshold *

0 - 6	7 - 12	13 - 16	17 - 20
Fast	Moderately Fast	Moderately Slow	Slow

/20

Score

The Slow Home Test evaluates how well a property conforms to the Slow Home Philosophy of being simple to live in and light on the environment. Plot your score on the bar graph and refer to the summary on the reverse page to interpret your results.

** Properties that score below the Minimum Design Quality Threshold (13/20) don't sufficiently conform to the Slow Home philosophy and are not very simple or light places in which to live.*

Understanding Your Score

FAST HOUSE (Score: 0 - 6)

If the property has a test score between 0 and 6, it's a fast house. 10% of North American residences have a score in this range.† These properties are badly designed with significant flaws throughout almost every part of the house. They will most likely be very difficult to live in and have a very high environmental footprint. Purchasing a property with a score in this range is not recommended. If this a residence you already own, caution is advised before undertaking any kind of remodeling. In most cases, not even a substantial project will be enough to fix the severity of the problems found in a fast house.

MODERATELY FAST HOUSE (Score: 7 - 12)

If the property has a score between 7 and 12, it's a marginally fast house. 47% of North American residences have a score in this range.† These houses have more poor design features than good ones. As a result they're not very simple to live in or light on the environment. However, they can often be gems in the rough if you're willing and able to undertake a major remodeling project. Whether this is a residence you're considering to purchase, or one you already own, it's important to proceed carefully and fully investigate the potential costs and benefits of making the necessary improvements.

MODERATELY SLOW HOME (Score: 13 - 16)

If the property has a score between 13 and 16, it's a marginally Slow Home. 32% of North American residences have a score in this range.† These properties have a good underlying design and there are problems in only a few areas. They're already quite simple and light places in which to live. However, a minor remodel can often upgrade them to a Slow Home. If this is a property that is currently listed for sale, it should be given very serious consideration. If it's a house you own, congratulations, you already live in a well designed residence that, with a few small improvements, could become really great.

SLOW HOME (Score: 17 - 20)

If the property has a score between 17 and 20, it's a Slow Home. Only 11% of North American residences have a score in this range.† Its underlying design conforms to almost all of the Slow Home criteria for a high quality of life. Very little if anything needs to be done to improve the design and any improvements are probably relatively minor and easy to complete. Whether this is a property you already own or one that you are considering to buy, you should feel confident knowing that this is a great home that is simple to live in and light on the environment.

† Based on the results of the *2010 Slow Home Report on Design Quality in the North American New Home Market*, Calgary: Slow Home Studio, 2011.

slowhomestudio.com

(Brown & North, 2010)

Appendix B – Design Guidelines for Dividing Suburban Homes

Basic Design Guidelines for Dividing Suburban Homes

The following design guidelines are meant to help homeowners with preliminary design and assessment of possible divisions and additions they could make to their home. The guidelines presented here provide a good starting point and cover the main design considerations for general space use in home. This is not a comprehensive list and does not replace the work of a professional architect or experienced home designer.

The left column describes the area of the home the guidelines apply to. The right column lists the design guidelines for that area of the home.

Design Area and General Notes	Design Guidelines
Whole Home Whole home design guidelines relate to the wider aspects of the home or to multiple rooms in the home	1. Design the new divided homes as if they were cottages. Cottages best reflect how people *actually* live rather than how people *think* they live. Cottages contain only what you need (Susanka, 2002) 2. Bigger is not better. More is not better. Oversized appliances, fixtures or rooms often indicate wasted space and money (Brown & North, 2010) 3. Square rooms are better than rectangle rooms. They are more adaptable to future uses than oddly shaped rooms and are easily furnished (Friedman, 2002; CMHC, 1999a) 4. Make rooms similar in size so they can change functions later when new occupants move in or when the current occupant's situation changes. Ex. A bedroom becomes an office (Friedman, 2002) 5. A room's smallest dimension should not be less than 9 feet (except bathrooms, closest, laundry spaces, etc) (Friedman, 2002) 6. Living, dining and master bedrooms should measure between 12 ft x 12 ft and 15 ft x 15 ft. (Friedman, 2002) 7. Rooms need focal points (TV, fireplace, etc) to 'ground' them (Wilson & Boehland, 2005; Brown & North, 2010) 8. Place doors near corners of rooms to maximize space use (furniture placement, circulation, etc). This way they don't cut a room in half

	(Friedman, 2002) 9. Walls should meet at 90º and should not be curved or angled. Angles and curves waste space and make rooms awkward to use and furnish (Brown & North, 2010; Freidman & Sheppard, 2004) 10. Complex geometries (jut-outs, many large dormers, etc), especially on the outside of the home increase the energy needed to heat the home as well as the materials needed to build the home. They are more expensive homes (Wilson & Boehland, 2005) 11. Size bachelor and 2 bedroom apartments at 500 square feet and 800 square feet respectively (Friedman, 2002). 12. Sound barriers are good in single-family homes but a must in multi-family dwellings (Pantelopoulos, 1993; Friedman, 2002; Wilson & Boehland, 2005). Acoustic boards and carpet work well (Friedman, 2002)
Zoning the Home Zoning is the practice of grouping rooms with similar functions or needs together	13. Group similar rooms together to allow services to be run together (Friedman & Sheppard, 2004). Ex. Put kitchen and bathroom back-to-back and run plumbing together (Friedman, 2002). This saves money. 14. Zone rooms by 'day' and 'night' and 'public' and 'private' use. Put the day functions where they will get light. Ex. living areas on south (lots of sun) and bedrooms on north side (little sun) (Friedman & Sheppard, 2004). Put private rooms in one area of the home and public rooms in another
Circulation and Hallways	15. Minimize circulation space as much as possible. It is often wasted space and use it instead for useful living areas (Friedman, 2002; Susanka, 2000) 16. Rooms should not function as circulation space. Ex. The path from the front door to the living room should not cut diagonally across the kitchen (Friedman, 2005)
Storage and Space Usage	17. Storage is very important. A home will never have enough storage, but anticipate needs and be creative when designing storage (Friedman & Pantelopoulos, 1996) 18. Built-ins save space in small homes where stand-alones can look crowded. Ex. build in couches, use shelves as walls, put storage in window alcoves below a built-in seat. Get creative (Susanka, 2002) 19. Build over vaulted ceilings to make/extend second floor area and make an alcove below. Alcoves feel "cozy" and are heavily used while vaulted ceilings look impressive but are not comfortable (Susanka, 2002

Lighting	20. Windows and natural light make spaces feel larger than they are and save energy on lighting (Friedman & Pantelopoulos, 1996) 21. Have large windows in the basement to let in light (Friedman & Sheppard, 2004).
Home Entry Entries give the first impression of the home (Freidman, 2005). A bad first impression is hard to fix even with good design in the rest of the house (Susanka, 2002).	22. Entries should be given their own space and should not be part of another room (Freidman, 2002; Brown & North, 2010) 23. Make entries large enough for 2-3 people to converse (Friedman, 2005) 24. Have storage nearby for coats, shoes, umbrellas, etc. (Friedman, 2005) 25. Entries should not enter directly into a main living area (Brown & North, 2010)
Kitchens Kitchens are multi-purpose rooms where bills are paid, conversations are had and children do homework. They are social hubs and can be the most important room in the house (Panelopoulos, 1993)	26. Kitchens should look out over the family room so parents can watch children from the kitchen and the chef can interact with the rest of the family or guests (Panelopoulos, 1993) 27. Use an island or peninsula with a raised eating bar to hide the kitchen mess from the dining room (Susanka, 2002) 28. 3-3½ feet between an island or peninsula and the main counter is a good guide (Brown & North, 2010) 29. Maintain continuous work surfaces for ease of use (Susanka, 2002) 30. Properly size the "work triangle" formed between the fridge, sink, and stove (Susanka, 2002)
Dining Room Dining rooms are multipurpose rooms where bills are paid, conversations are had and children do homework.	31. One dining room is almost always enough. Formal dining rooms are hardly used and the space is better used for other functions (Friedman, 2002; Brown & North 2010) 32. Table should be appropriate size and shape for the intended use and room size (Brown & North, 2010).
Indoor Living Space (Living Rooms, Family Rooms, Great Rooms, etc)	33. A family home must have two living spaces, a primary one and a secondary one. Children can go to this space when the adults have company over and vice-versa (Pantelopoulos, 1993). They also eliminate conflicting uses like reading and watching TV and conversing. 34. Living spaces must have a connection with the outdoors such as sight

	lines, large windows, patio or deck access etc. 35. Size must allow for appropriate furniture given the function. A small living room for a large family will be hard to furnish 36. Circulation room around furniture should be minimal but not cramped
Den, study, home office	37. Dens, studies, home offices, etc. are very important especially as more people need an area for their computer and computer work. The exact needs of this space in terms of privacy, size, and amenities vary widely depending on use (Pantelopoulos, 1993).
Bathroom	38. Use traditional (basic) layouts – they are most functional (Brown & North, 2010) 39. Avoid oversized fixtures to keep costs down and save space (Brown & North, 2010) 40. Ensure appropriate counters space and storage space is available (Brown & North, 2010) 41. Shared bathrooms force siblings to learn to cooperate and share but are not desirable in homes with unrelated adults (Pantelopoulos, 1993) 42. Two bathrooms per family is optimal. One can suffice but is an annoyance. Three is too many (Friedman & Pantelopoulos, 1996) 43. When opposite the tub, there should be 5ft between the back of the toilet or sink and the tub (Brown & North, 2010) 44. Place washrooms in a private but accessible place. Ex. Off of the main entrance or garage entrance, but NOT directly off of the dining room or kitchen (Brown & North, 2010).
Bedrooms Are often used for children's play and work in addition to sleeping, so design bedrooms for these functions as well (Pantelopoulos, 1993).	45. Use 10 ft as a general minimum dimension (Brown & North, 2010) 46. Must have natural light and natural ventilation (Brown & North, 2010) 47. Incorporate a functional closet, preferably embedded in the wall and not jutting into the room (Brown & North, 2010) 48. Do not make the master bedroom into a bedroom-living room combination. This extra living space is rarely used. However, a small seating area can be a useful way to create a second living space in small homes (Wilson & Boehland, 2005)
Outdoor Living Space	49. Every home *must* have access to a private outdoor space (Brown &

A connection to the outdoors is vital and should not be underestimated. Outdoor space can double as living space and should follow similar design principles as living spaces (Brown & North, 2010).	North, 2010; Wilson & Boehland, 2005) 50. This space should act as an extension of the indoor living space and should be connected in some way to the indoors (Brown & North, 2010; Friedman, 2005) 51. Orient the space with the sun whenever possible (Brown & North, 2010) 52. There should be at the very least enough room to comfortably fit a small eating table with chairs and a barbeque (Brown & North, 2010)
Accessibility	53. Take into account accessibility. Who will be using the space and what will their requirements be? (Friedman, 2002) 54. People with disabilities and the elderly will need amenities such as turning room for wheelchairs and walkers and grab bars for baths and stairs (Friedman, 2002)

APPENDIX C – UNIT CONSTRUCTION COSTS FOR DIVIDING HOMES

Item	Description	Unit	Cost/Unit	Source
General Carpentry				
Wall Construction	2"x4", 16" O.C., dbl top plt, sngle bot plt, 5/8" dwl taped finish paint both sides, insul, basebaord, 8' high, installed	sf	$8.63	R.S. Means, 2005
Wall Demolition		sf	$2.48	R.S. Means, 2005
Door Removal	Single interior door	each	$21.03	R.S. Means, 2005
Fire Door	90 min rating for between units	each	$349.33	R.S. Means, 2005
Interior Door	Hollow core, 1-3/8", 6'8"x3"	each	$203.18	R.S. Means, 2005
Interior Door Install Only	Hollow core, 1-3/8", 6'8"x3"	each	$34.46	R.S. Means, 2005
Sliding Door	6'x6'	each	$1,782.28	R.S. Means, 2005
Trim	Stock pine, 11/16"x1-3/4"	lnft	$3.37	R.S. Means, 2005
Deck Construction	PT, 16" OC	sf	$14.73	R.S. Means, 2005
Flooring				
Ceramic Tile	Mid-Range Quality	sf	$5.50	QFC*
Carpet	Mid-Range Quality	sf	$6.00	QFC*
Hardwood	Mid-Range Quality	sf	$3.00	QFC*
Kitchen				
Cabinets	Non-custom, prefinished, average quality, wall and base, installed	each	$12,000	Ikea, 2010; G.Z.**
Microwave	Mid-Range Quality	each	$300	Future Shop, 2012
Dishwasher, built-in	Mid-Range Quality	each	$525	Future Shop, 2012
Range	Mid-Range Quality	each	$1,000	Future Shop, 2012
Range Hood	Mid-Range Quality	each	$250	Future Shop, 2012
Fridge	Mid-Range Quality	each	$1,000	Future Shop, 2012
Bathroom				
New Bathroom	Average 3 pc incl all fixtures	each	$9,000	J.M.***
Plumbing				
New Fixture	Plumbing fixture install	each	$600	J.M.***
Electrical	New wiring as required		$10,000	J.M.***

*Quality Flooring Canada, personal communication, July 13, 2010
**G. Zilberbrandt, personal communication, July 13, 2010
***J. Malavolta, personal communication, July 14, 2010

APPENDIX D – SUSTAINABLE ADDITIONS MODULE

CHOOSING SUSTAINABLE BUILDING MATERIALS FOR ADDITIONS TO SUBURBAN HOMES

This is a decision support system (DSS) to help suburban homeowners select building materials for additions. **Only exterior wall building materials and their insulation are considered**. The other components of the home such as the roof and foundation have fewer opportunities for unique sustainable material selection and have not been included. Interior finishes such as floor coverings and paints are also not included. There are many books and guides to help homeowners choose environmentally friendly interior finishes. Since interior finishes are not structural, there is more flexibility for the homeowner to be creative with sustainable or recycled materials.

For this DSS to be applicable, additions must be a continuous space of at least 23 square meters (250 square feet), or about the size of a new kitchen and living room combined. The cottage in Figure 1 gives a rough estimate of this size. At this size, it starts to make sense to use the building materials suggested here. It is assumed that homeowners will not necessarily be renovating the rest of the home for energy efficiency. This means that the building materials themselves should be as sustainable as possible.

Figure 1: A straw bale cottage about the minimum size recommended for using straw bale, adobe, or rammed earth (StrawBale Innovations, LLC, 2011)

A review of various building materials was completed. From this review, six sustainable building materials were selected for further study. Table 2, shown below, was completed to help determine the best building materials. Each material was investigated and given a score. After completing this chart is was found that **straw bale construction, adobe construction** and **rammed earth construction** were the most sustainable building materials. The other methods considered are not as sustainable. More information on the scoring system can be found below Table 2.

From an aesthetic and architectural perspective, straw bale construction, adobe construction and rammed earth construction are extremely versatile. They can be made to look quite unique with curved walls and interesting built-in features like those in Figure 2 or they can be made to look like a conventional home, no different from others in the neighbourhood.

Choosing your Building Material

A good and sustainable building material is one that is well suited to the local climate and uses locally available materials. Most building methods used in residential construction do not meet these criteria. Most methods have been developed to perform acceptably in most places in North America. This is convenient because these methods can be used almost everywhere. But there is a tradeoff. The tradeoff is that they do not perform as well as building materials that are suited to specific climates. They also often have to be shipped long distances to the construction site.

Building materials that are selected for the local climate can perform better than conventional building materials. Materials that can be found locally do not have to be shipped long distances causing pollution. This DSS recommends using building materials that are appropriate for your climate and region. A brief explanation of where straw bale, adobe, and rammed earth work is outlined below.

Figure 2: The interior of the straw bale cottage shown in Figure 1. A finished adobe wall is remarkably similar looking to the walls shown here and in Figure 1 (StrawBale Innovations, LLC, 2011)

Straw Bale Construction

As a guide, straw bale can be built anywhere that has access to straw (not hay) and is not overly hot and humid. Excessive humidity combined with heat *may* pose moisture and rot problems problem, but not necessarily. Recent research has shown that when built properly, moisture will not be a problem for most of North America, including the temperate and rainy coastal regions. More research is needed to confirm whether or not the American South-East is appropriate for straw bale. It may be acceptable to build there, but until the research has been completed, this DSS does not recommend straw bale in that area. Figure 5 shows a climate map of North America and indicates the area in question.

Straw is grown commercially in all Canadian provinces except Newfoundland and Labrador and the Territories. This means that straw can be sourced locally in most provinces. Straw is grown commercially in all continental states in the US. There may be issues in finding local straw in some areas of the southwest and Maine.

To sum: if you live near agricultural fields and the location is not hot and humid as indicated in Figure 5, straw bale can be used.

Figure 3: A rammed earth home. Notice how the walls can be sided with wood for a conventional look or left bare to show the rammed earth walls (Schooly, 2008)

Adobe and Rammed Earth

Adobe and rammed earth are very similar building materials and can be built in the same places and same climates. Both adobe and rammed earth are soil-based. This soil must the right type and composition (loam, clay, silt, etc). North America has a wide diversity of soil types and so many places will have the right soil type somewhere in the region.

Adobe and rammed earth have great thermal mass properties and can moderate large daily temperature swings (cold at night and hot in the day for example). They do not have good insulation levels and need to be insulated in places where there are long periods of hot or cold temperatures. They can be insulated to high levels with extruded foam panels if needed. In places where the *average* outdoor temperature is usually between 18°C and 25°C (64F – 77F), adobe and rammed earth do not need insulation. All locations in Canada will require insulation and most of the US will as well. Figure 6 shows the average daily temperature for the entire US.

Figure 4: The layers of soil in a rammed earth wall (Schooly, 2008)

To sum: In hot or cold climates pick straw bale when there is local straw available, unless it the climate is hot and humid as shown in Figure 5. Adobe and rammed earth are recommended in places where *average* outdoor temperature is between 18°C and 25°C most of the year. Figure 6 shows the average daily temperature for the United States. If the climate is hot or cold and local straw is not available, pick adobe or rammed earth with insulation. Since adobe and rammed earth are such similar building materials, it is the homeowner's preference on which one to choose.

To help clarify selecting building for your location Table 1 has been included. It shows the recommended building materials for various locations throughout North America. All locations in North America will answer the questions in Table 1 the same as one of the example locations.

From this information a choice on building materials can be made. Table 2 below is the chart that was used to select straw bale, adobe, and rammed earth construction over other methods. Also found below is an explanation of the different criteria and notes on how the chart was complied for those interested.

For further information on straw bale, adobe, and rammed earth, click the links to the primers on the DSS main page, beside the link that opened this document. The primers will provide some more introductory information as well as links to more comprehensive sources of information.

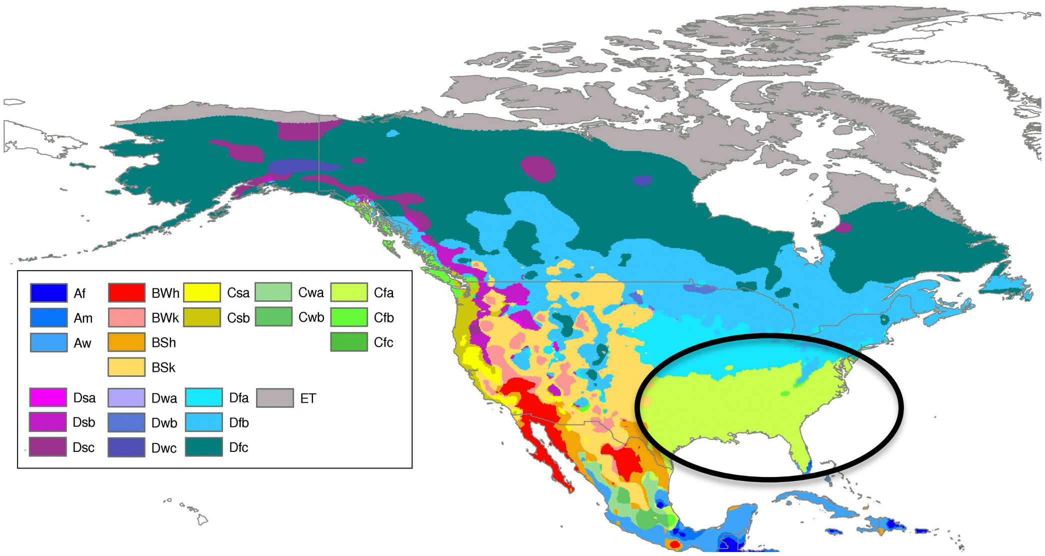


Figure 5: Koppen-Geiger Map of North America - More research is needed to determine if straw bale is appropriate for the American south-east, the circled light green area above (Peel, Finlayson, McMahon, 2007)

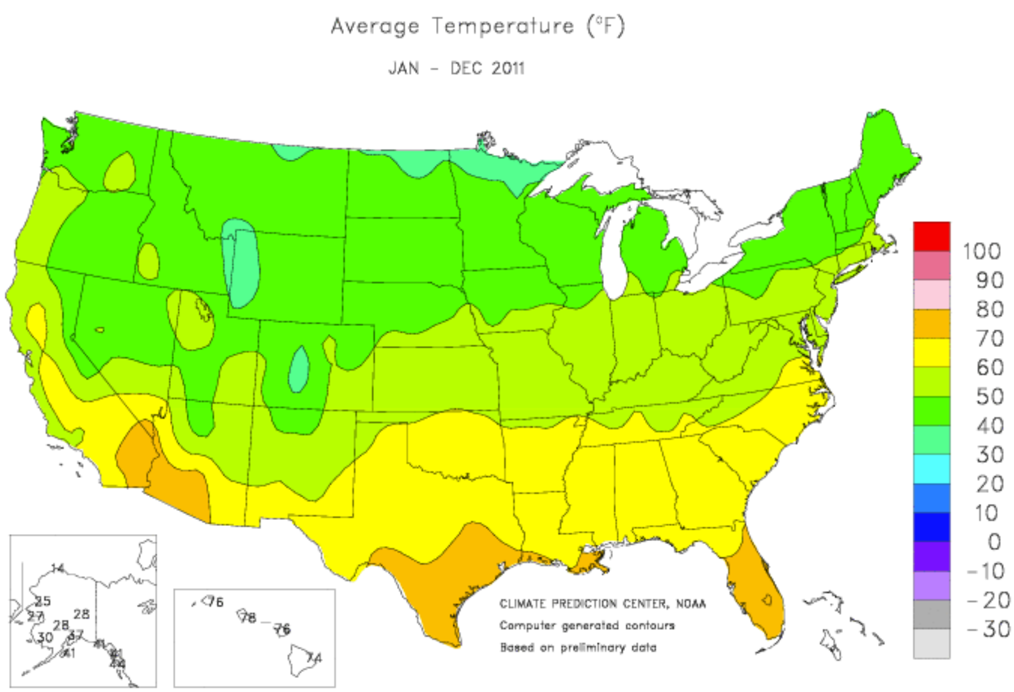


Figure 6: US average daily temperature (National Weather Service, 2011)

Table 1: Recommended Building Materials in Representative Locations

Location	Does Straw Grow Locally?	Daily temperature between 18°C (64F) and 25°C (77F)?	Is it Hot and Humid?	Recommended Building Material*
St. John's, NL	N	N	N	Insulated rammed earth or insulated adobe
Phoenix, AZ	N	Y	N	Rammed earth or adobe
Toronto, ON	Y	N	N	Straw bale
Los Angeles, CA	Y	Y	N	Straw bale, rammed earth, or adobe
Miami, FL	Y	Y	Y	Rammed earth or adobe

*rammed earth and adobe recommendations are not insulated unless otherwise indicated

Table 2: Selection Chart Used for Picking Building Materials

Criteria* / Building Method*	Embodied Energy	Resource Conservation	Extraction Impacts	Indoor Toxicity	Recyclability	Ease of Construction	Cost	Total (/21)	Scaled (%)
Stick-Frame	2	1	2	3	2	3	3	16	**76**
Insulated Concrete Form	2	1	2	2	1	2	2	12	**57**
Insulated Structural Panel	2	1	2	3	1	3	3	15	**71**
Straw Bale	3	3	3	3	3	1	2	18	**86**
Adobe	3	3	3	3	3	1	2	18	**86**
Rammed Earth	3	3	3	3	3	1	2	18	**86**

- Ratings range from 1 to 3; 1 = Poor Environmental Performance; 3 = Excellent Environmental Performance
- Each criterion was weighted equally. For example, Recyclability was deemed to be just as important as Resource Conservation
- Thermal Performance (insulation) was excluded since all methods can be built to perform equally in this category
*See below for information on criteria and building methods

Criteria and Building Method Notes

Embodied Energy: Embodied energy takes into account the energy required to produce a material including procurement (extraction, mining, etc), transportation and manufacturing, but not labour.

Resource Conservation: Considers if the resource is renewable at current rates of production.

Extraction Impacts: How disruptive is the extraction to local ecosystems? Considers if the impacts are negative, neutral, positive, or reversible.

Indoor Toxicity: Some building materials contain substances that are harmful to humans and can cause health problems.

Recyclability: Can the materials used be easily recycled and how much waste is produced?

Ease of Construction: Takes into account both the complexity of the building method and if there are builders and practitioners widely available to construct with this material or method. Methods that are easier to build with can be cheaper or more easily completed.

Cost: Relative to the other construction methods, how much does this method cost to construct?

Stick-Frame: Assumes a wall system of: vinyl and/or brick veneer cladding, OSB sheathing, 16ioc stud frame, fiberglass insulation, and drywall. Non-FSC wood. Super insulated.

Insulated Concrete Form (ICF): Assumes a wall system of: brick veneer, ICF, and drywall. ICF contains concrete core sandwiched between extruded insulating foam.

Insulated Structural Panel: Assumes a wall system of: vinyl and/or brick veneer, ISP, and drywall. ISP is an extruded foam core sandwiched between OSB sheathing.

Straw Bale: Assumes load-bearing construction. Wall system is straw bales plastered with earth-based plaster. Location is close to agricultural areas to supply straw bales.

Adobe: Assumes home is built in area that needs no added insulation, local soils are used for construction of adobe bricks and plaster and that soil can be sourced locally.

Rammed Earth: Assumes home is built in area that needs no added insulation, local soils are used for construction of walls and that soil can be sourced locally.

Permeable Paving

Permeable Paving

Hard surfaces (also called impervious surfaces), cover a significant amount of suburban residential property. They include driveways, roofs, concrete walkways and patios, and other such surfaces. They are *impervious* to water, meaning water cannot soak through them. Permeable paving is paving that is *pervious* to water. That means water can seep through and then soak into the ground.

There are many types of permeable paving that can be used for driveways, walkways, patios, and other hard surfaces. Some examples are: lattice pavers for driveways, flagstone for walkways, and decks in place of concrete patios.

The examples shown here are mean to give some ideas and inspire ways to decrease the amount of hard surface on your property. In general, just keep in mind the goal is to remove or replace as many hard surfaces as possible. They can be replaced by permeable paving, such as those shown here, or simply replaced by grass or a garden. There are many ways to reduce the amount of hard surfaces on your property that are not shown here but will work just as well.

One must be careful of *porous paving* or *porous concrete.* This is a special type of permeable paving that looks and acts much like traditional concrete except it has many little pores similar to a sponge. Water seeps through the pores and into the ground. This type of paving is not appropriate in freezing climates. In cold climates, such as Canada and the Northern States, if water seeps into the pores and then freezes, it can crack the pavement (Riversides, 2009).

Further Reading
Stormwater Management Resource Centre
- http://www.stormwatercenter.net/Assorted%20Fact%20Sheet
- http://www.stormwatercenter.net/

Clockwise from top left: Flagstone pathway in place of concrete pathway; lattice paving with plantings in holes (Riversides, 2009); patio pavers placed only where required creating a driveway with filter strips (Riversides, 2009); and a small gravel driveway in place of a large asphalt driveway (Weems Creek Conservancy, n.d.)

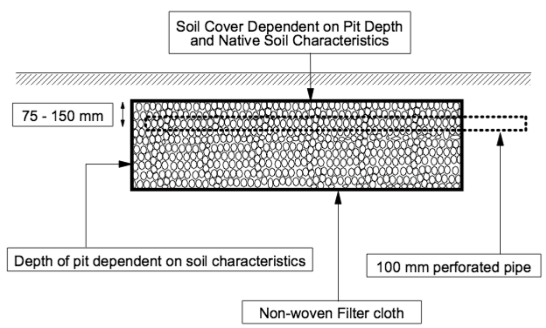
Soakaway Pits

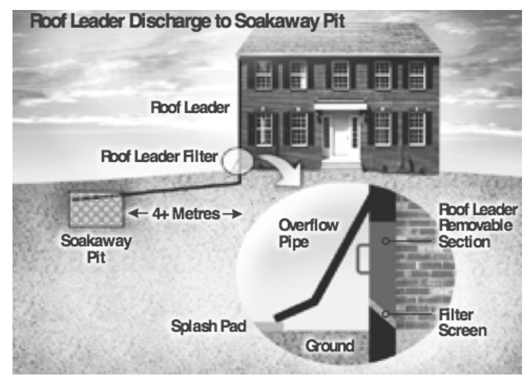
Introduction

Soakaway pits are large holes dug in the ground and filled with crushed stone. Stormwater is directed to the pit where it slowly soaks into the ground. They are covered with soil and plants or grass after installation hiding their existence. They can be used when rainwater harvesting is not used or when the rainwater harvesting system frequently overflows. They are more expensive than a basic rain barrel or yard ponding system but serve the same purpose. They can be beneficial because they are low maintenance and do not take up space in a residential yard. If possible, first attempt to manage stormwater with yard ponding because it is cheaper. Soakaway pits should be designed by a professional but for basic sizing see the Soakaway Pit Sizing Tool (OME, 2003).

Design Considerations

- Locate pit at least 4m away from foundations
- The native soils must have an infiltration rate of 15mm/h or greater. Loam or any more porous soils should work
- Line the entire pit with non-woven filter cloth to stop the surrounding soil from clogging the stone
- The leader pipe from should extend into the length of the pit and be perforated to allow for water to be discharged evenly as shown below
- Filter the water with a screen before it enters the pit. Failure to screen the water will result in clogging and rapid failure
- Accommodate overflow with a splash pad
- The pit's length (direction of the flow) should be maximized compared to the width to help the water soak into the surrounding soil
- Pits any deeper than 1.5m will cause compaction of the native soils and slow or stop infiltration
- Do not locate pits near areas where vehicles are parked or driven





Photos: Left, leader pipe (downspout) extends pit length and pit is lined; Right, Overflow accommodation (Ontario MOE, 2003)

Further Reading
Understanding Stormwater Management: An introduction to Stormwater Management and Design. Ontario Ministry of the Environment (2003). http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079720.pdf

Yard Ponding

Introduction

Yard ponding is one of the most basic and cheapest methods for managing stormwater. It is a good first choice for stormwater management. Essentially the house's downspout (leader pipe) is directed to a place in the yard where water can pool and soak into the ground over time. If the soil has the proper infiltration this can be easily done. Many homes already do this.

Water should not be left standing and should seep into the ground over a short period of time (approximately 24 hours). Their drawback is that while in use (after a rainfall), a portion of the yard will be wet until the water has soaked into the soil. If water can easily soak into the ground, no alteration of the ground will be required and homeowners can simply direct water from the downspout to the lawn. This is called downspout disconnection because the downspout has been disconnected from the municipality's stormwater system.

Before digging a ponding area, it is advised that homeowners simply direct their downspout to a spot on their lawn that will allow the water to soak in. Test this arrangement over an extended period of time and if it works, then no further action is required. If standing water is taking up large yard space, then ground alteration (replacing poor soil with good soil) may be required. This would involve creating a depressed area in the yard or creating a berm to hold water and then directing the water to this area (Ontario MOE, 2003).

Design Considerations

- Native soil must have infiltration of 15mm/h or greater (Loam or any more porous soils)
- Minimize the depth of the ponding area by making it wide and shallow, not small and deep; the depth should not exceed 100mm
- The ponding area should be at least 4m away from buildings
- Even flow over the ponding area will improve infiltration rates. This can be achieved by using downspout leader with holes as shown in the figures below
- Use a screen to remove debris that may clog the perforated pipe

Left and Centre: Perforated downspout for even water dispersal
Right: Depressed yard pond

Further Reading
Understanding Stormwater Management: An introduction to Stormwater Management and Design. Ontario Ministry of the Environment (2003). http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079720.pdf

Rainwater Harvesting

Introduction

Rainwater harvesting is a very simple stormwater management tactic. Rainwater is collected from the roof downspout, stored in a barrel and can then be used in a number of different ways like outdoor watering, indoor non-potable use (flushing toilets, washing clothes), or indoor potable use (drinking water).

The first step in designing a rainwater harvesting system is to decide what you want to use it for. If you want to use the water for outdoor watering, the system will be quite cheap and easy to install. If it is for indoor use, it will be more complicated and expensive. You must make sure that by-laws allow for rainwater use in the home and will probably want to time the installation with another planned renovation because installing the pipes inside the home requires opening up walls and can be quite costly.

If the water is to be for outdoor use, simply attach the house's downspout to the appropriately sized barrel, put on a filter screen, and hook up a hose to use the water. This is very cheap and has a positive impact on stormwater runoff from your property. The figure to the right shows a good rain collection system for outdoor use.

If the water is to be used for indoor use, hire a professional for the system design. Rainwater on its own is often not enough to meet household needs, but if used with water recycling it can often be sufficient. If collecting for drinking use, the roof must not be made of a material that can leach chemicals into the water. Aluminum and clay tiles will not leach but asphalt shingles will.

Design Considerations

- Hire a professional if you intend to use water indoors
- For potable use you can't have asphalt shingles
- Filter debris out of the water after running off the roof
- Account for overflows – direct an overflow pipe away from the house and onto the yard
- A very small rainfall can quickly fill a small barrel so you may need more than one barrel

Photo: This rain barrel is used for outdoor irrigation. It has a screen filter on top and an overflow pipe linking it to another barrel. This system also has the option of diverting the downspout to a ponding area – something that is convenient but not required

Further Reading

- Towards Net Zero Water: Best management practices for decentralized sourcing and treatment, Cascadia Green Building Council (2011). https://ilbi.org/education/reports - good introduction for indoor use
- There are numerous websites explaining various ways of setting up rain barrels for outdoor irrigation use

Xeriscaping/Lawn Naturalization

Introduction

Lawn Naturalization is when non-native and exotic plants are replaced with native plants. Ideally these plants will simulate naturally occurring habitat. *Xeriscaping* is very similar to lawn naturalization but uses plants (often native) that don't need watering to cut down on water use. Lawn naturalization and xeriscaping will be referred to as *naturalization* from here on.

Naturalization has many benefits, the main one being the recreation of natural habitat but also include: increasing biodiversity, attracting wildlife (birds, bees, butterflies), reducing the amount of water needed for irrigation, eliminating the need for lawn chemicals, filtering stormwater, reducing lawn and yard maintenance and creating a beautiful yard.

A naturalized lawn does not always mean the complete elimination of a traditional grass lawn. There are options for lawns that use native grasses. Some of these grasses require far less maintenance than traditional lawns. Since the plants used for naturalization depend on the wants and needs of the owner, each yard will be different. The two recommended readings are excellent places to start learning more. There are also many books on natural gardening and naturalization of yards.

The basic principles of gardening still apply to naturalization so those who are already gardeners can easily begin to naturalize Those who are not gardeners or dread the thought of a having more gardens to maintain should not worry. A naturalized yard can easily be designed to be low maintenance and after they are established they require very little work, about the same as cutting the lawn.

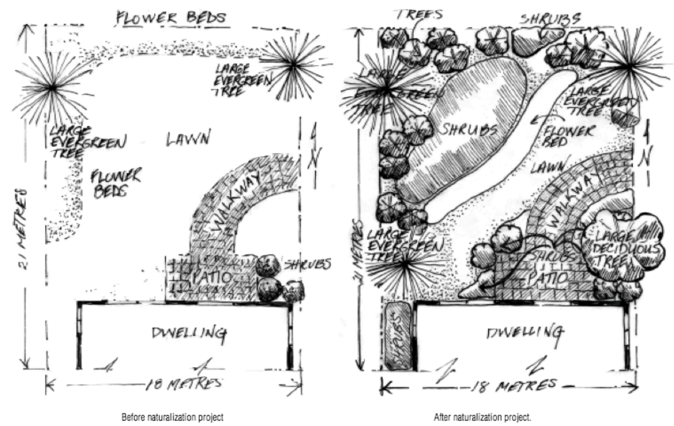


Photo: A diagram of a naturalized lawn before and after

Recommended Reading
- Canadian Wildlife Federation's Wild About Gardening site: Sitehttp://www.cwf-fcf.org/en/what-we-do/habitat/wag-home.html
- *Naturalizing Your Local Park or Backyard* by the Rideau Valley Conservation Authority: www.lrconline.com/Extension_Notes_English/pdf/Naturalize.pdf

Rain Gardens

Introduction

Rain gardens are special gardens designed to filter and manage stormwater. They can be beautiful and create habitat for beneficial insects as well. Raingardens use specially selected plants and soil that are able to filter water. To capture water, runoff from a rooftop, driveway, or lawn is directed to the garden where it soaks into the ground (Davis et al, 2009). They would be used in similar situations as yard ponding or soakaway pits but where a more attractive alternative is wanted.

Generally native plants are selected for the garden because they are adapted to the local climate and local conditions as well as for aesthetics. Rain gardens can be quite beautiful, provide habitat for local wildlife such as birds and insects, and as a significant landscape feature, add value to the home (Prince George's County, 2007).

Essential reading is the *Rain Gardens: A How-To Manual for Homeowners,* listed below. It provides a sizing tool and excellent guidelines for designing and building rain gardens. Keep in mind that this document was specifically written for Wisconsin and the plants listed are for that region. You should select plants based on your specific region.

Design Guidelines

- Place garden at least 3m from any building foundation
- Do not place near septic systems
- Do not place where water ponds naturally
- Place on flat part of yard
- Sizes range from 9.3 m^2 to 27.9m^2 (100-300 sq. ft.) – if a larger garden is needed they should be split into two separate gardens
- Depth should be 10-20 cm (8-20 in)
- Length should be about twice as long as width
- Maximum width should be 4.5m (15 ft)
- Place length of garden perpendicular to water flow
- Use a diversity of plants, this allows proper root competition and growth

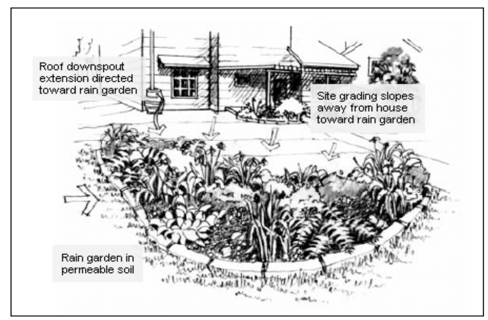


Photo: Rain garden diagram (CMHC, 2004b)

Further Reading

- Rain Gardens: A How-To Manual for Homeowners. Wisconsin Department of Natural Resources, Publication number PUB-WT-776 2003.
*www.dnr.state.wi.us/org/water/wm/dsfm/shore/documents/rg**manual**.pdf*
- *Rain Gardens: Improve Stormwater Management in Your Yard*. Canada Mortgage and Housing Corporation. (2004). http://www.cmhc-schl.gc.ca/en/co/maho/la/la_005.cfm

Grey Water Reuse

Introduction

Grey water is wastewater that comes from any drain in the home except the toilet. Toilet wastewater is called black water. Grey water is less contaminated than black water and can be easily treated for non-potable use and with more treatment, brought back to potable use. Non-potable uses include toilet flushing, outdoor irrigation, and clothes washing.

There are a few different treatment systems that can be used to treat grey water. They range from simple filtration if the water is only being used for toilet flushing, to more extensive treatment if the water is being used for sensitive used like clothes washing .

Grey water systems can be expensive to install on their own because new pipes must be run through existing walls and old plumbing must be re-routed. Therefore grey water systems are best installed during other renovations when plumbing will be exposed anyway.

There are currently very few regulations in many municipalities governing grey water reuse and in some places it is illegal. It is important to ensure that this system is installed legally and is designed and installed by a qualified professional (CGBC, 2011).

Design Considerations

- Do-it-yourself kits run the in the $1000 range while proprietary systems can cost between $2500 and $8000.
- Water savings of 15,100 L (4000 gal) to 22,700 L (6000 gal) annually are a reasonable estimate

Photo: A diagram of a grey water reuse system that uses sink water for toilet flushing (WaterSaver Technologies, 2009). This is one of many different options available for reusing grey water.

Further Reading
- Cascadia Green Building Council (CGBC). (2011). *Toward net zero water: Best management practices for decentralized sourcing and -treatment.* Portland, OR: Cascadia Green Building Council. Available online from the International Living Futures Institute at https://ilbi.org/education/reports

Wastewater Treatment

Introduction

The two main options for residential wastewater treatment are: constructed wetlands/living machines or bio filters.

Constructed wetlands are based on the same water filter processes used in wetlands: plants, soils, and organisms work together to filter water. They can be sized for single-family homes or shared by multiple homes. A clarification tank that removes solids will be needed before the water enters the wetland. The water is usually not open to the surface (it runs through the soil) to minimize odours, bugs, and human contact.

Biofilters are robust treatment systems that are composed of a large tank filled with porous material such as rock, plastics, or organic material. This porous material provides a surface for microbial growth and these microbes then treat the water. Like constructed wetlands, they also need to use a clarification tank before treatment. They are modular in design, lending themselves well to expansion and are able to handle overloads for extended periods. Biofilters can treat water to very high standards.

Photo: Diagram of a constructed wetland (CGBC, 2011). Biofilters (not shown here) would take up less space and can buried underground similar to septic tanks

Design Considerations

- Further treatment is needed if water will be used for drinking
- Costs – Constructed wetland: $10,000 to $15,000 for a residence; Biofilter: $3000 - $10000 for a residence
- They can work in cold climates with proper design
- When used with composting toilets, their costs can be minimized
- Constructed wetlands need about 300-400 square feet
- Biofilters are smaller than constructed wetlands and can be buried
- Very little energy is needed for operation but both need regular maintenance

Further Reading

- Cascadia Green Building Council (CGBC). (2011). *Toward net zero water: Best management practices for decentralized sourcing and -treatment.* Portland, OR: Cascadia Green Building Council. Available online from the International Living Futures Institute at https://ilbi.org/education/reports

Composting Toilet

Introduction

Composting toilets are toilets that turn human waste into compost and use very little or even no water. When operated properly the compost will be safe to handle. Composting toilets look similar to normal toilets except there is no tank (only a bowl) and the waste is held in a container below the toilet where it is composted. Some will also use electricity to operate a small fan to vent the composting chamber.

They can be a problem if they are installed in an existing home because the composting chamber be located below the toilet and takes up room. This means that composting toilets are best installed in new construction or during renovations when chamber space can be accommodated.

The compost can be used as fertilizer or simply spread in a natural area. Although the smell of composting toilets has been cited as a problem, advances in the technology and proper care and installation have eliminated this issue.

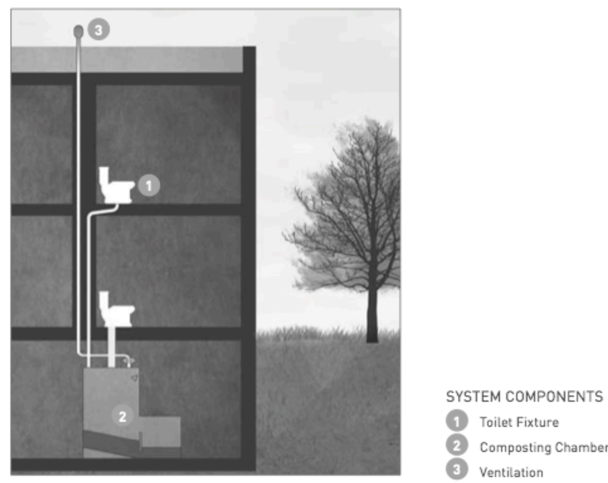
In new construction where a septic tank would be used, a composting toilet can be more cost effective. Composting toilet systems range from $1000 to $5000 and can have a relatively short payback period depending on water and sewer charges (CGBC, 2011).

Photo: Composting Toilet Diagram. Note the area needed below the toilet for the composting chamber (CGBC, 2011)

Design Considerations

- Use where there are water constraints
- Composting toilets work well in residential settings
- Two composting types:
  - Continuous process – composted material is removed from the bottom of the chamber while the top of the tank is still composting
  - Batch process – when full, the chamber is removed and set aside to compost and a new chamber is put in its place

FIGURE W-1: COMPOSTING TOILET



Further Reading

- Cascadia Green Building Council (CGBC). (2011). *Toward net zero water: Best management practices for decentralized sourcing and -treatment*. Portland, OR: Cascadia Green Building Council. Available online from the International Living Futures Institute at https://ilbi.org/education/reports

Night Ventilation
(Natural, Fan, and Stack Ventilation)

Introduction

Outdoor air can be used to cool the home. On summer evenings the outdoor air is often cooler than the indoor air. Brining in this cool air with specially designed windows or fans can cool the home. This can be very effective and much cheaper than air-conditioning. The basic idea is to keep heat out of the home during the day. This is done by insulating the home, shading the home and keeping windows and doors closed. Then at night open the doors and windows and turn on the fans to bring in the cool air. The home is then closed up again in the morning and the cool night air is kept in the home. This is called night ventilation.

There are a few main ways to move cool air into the home. They are: natural ventilation, fan assisted ventilation, and stack ventilation.

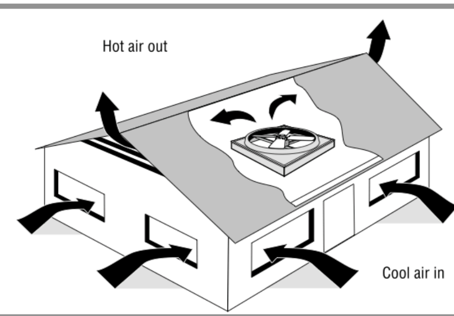
Natural ventilation uses windows and breezes to move air through the home. Specially sized and placed inlet and outlet windows help maximize the breeze.

Fan assisted ventilation uses a specially placed fan to move air through the home. Fans are more reliable than breezes. Fans are placed blowing outward as shown in the photo. They can be common floor fans or the more powerful whole-house fans.

Stack ventilation uses moving air over a tall stack (similar to a chimney) to create pressure differences between the high stack and a lower window. If a stack is not feasible then a high third-floor window can work as well.

Design Considerations

- Open floor plans work best, rooms without air flow cannot be cooled
- Air is able to move around corners to reach an outlet
- Both an inlet and outlet are required
- Good insulation is suggested but not required unless major renovations are taking place to accommodate the natural ventilation
- For natural ventilation, inlet should face the wind or be no more than 45° to the wind.
- The inlet should be smaller than the outlet for natural and stack ventilation



Photos: Fan assisted ventilation. The concept remains the same for all ventilation strategies (United States Department of Energy, 1999)

Further Reading
-The *Build It Solar* web page's Passive and Active cooling section: http://builditsolar.com/Projects/Cooling/passive_cooling.htm
-Brown & DeKay (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.
-Buckholder & Anderson. (2005). Be cool: Natural systems to beat the heat. *Home Power, volume 108, pgs* 20-25

Thermal Mass
(Cooling and Heating)

Introduction

Thermal mass is a material that can be used to store heat. Materials such as rock, concrete, ceramic tile, soil and water are very good at holding heat, almost like a heat battery. They are said to have 'good thermal mass'. Thermal mass can help stabilize the temperature in a building by eliminating temperature swings and serve as an energy storage device (Brown & DeKay, 2001).

Thermal mass can be used for both heating and cooling purposes. For heating, the sun comes through windows and heats the thermal mass, often a concrete or tile floor. The floor stores the heat and at night when it gets cool, the floor re-radiates the heat keeping the home warm.

Thermal mass can also be used to help keep areas cool. The mass is cooled at night often by blowing cool night air over it. It then remains cooler than the home for the rest of the day soaking up the heat of the day, keeping the home cool (Brown & DeKay, 2001). The earth's temperature (the soil underground) is often below the home's indoor temperature. This means it can be used to help keep the home cool by piling soil against a specially designed wall (Brown & DeKay, 2001). This is why the basements in many homes are cooler in the summer than other rooms upstairs.

Design Considerations

For heating:

- Ratio of glazing to masonry: 3-6ft^2 glazing/ft^2 masonry, masonry at 4-6 inches thick
- 145-265 L water/m^2 of floor area (water container can be any shape)
- Mass must be exposed to living space and to sunlight
- Mass should be 50% absorbent to light (darker in colour)
- If a home's south-facing glazing is more than 8% of the floor area, thermal mass will be needed

For cooling

- 1:1 – 1:3 Mass area:Floor area ratio, masonry at 4-6 inches thick
- Mass must be exposed to cool breezes and living space
- Mass should never be exposed to sunlight
- Earth berms are good mass – place on west side of home if possible

Photo: A concrete floor like this one can store heat from the sun shining through the large windows during the day and keep the room warm at night (Concrete Network, n.d.)

Further Reading

- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.
- The *Build It Solar* web page's Passive and Active cooling section: http://builditsolar.com/Projects/Cooling/passive_cooling.htm
- The *Built it Solar* web page's Solar Space Heating section http://www.builditsolar.com/Projects/SpaceHeating/Space_Heating.htm

Energy Efficient Landscaping

Introduction

Vegetation planted in specific spots outside the home can help reduce energy consumption. They can help cool in the summer and reduce heat loss in the winter. Plants can help cool in two main ways. First they can shade and block sunlight and heat from getting in the home. Secondly they can create a pocket of cool air around the home. This is done through evapotranspiration. This is why a forest is often cooler than a field. In addition to helping keep the home cool, trees and plants can help keep the home warm by acting as windbreaks, blocking cold winter winds.

General Notes Cooling With Vegetation

Large trees can provide excellent shade in the summer. But in the winter even deciduous trees can still shade the home and reduce wanted passive heating (McPherson & Rowntree, 1993). Fortunately there are some deciduous trees that can let in enough sunlight to still passively heart the home. The tree selection tool can help identify desirable trees. For shade, place plants on the east and west but not on the south. Unless the climate is very warm and little winter heat is needed, use overhangs on the south to block summer sun. See the shading and overhang tool for information on overhangs.

Bushes or trees that branch out from the base of the tree are good because they provide even shade coverage and are more predictable. Vines can be trained along trellises to provide a shaded canopy as well as aesthetic appeal. (Buckholder & Anderson, 2005)

Further Reading

- Buckholder, P. & Anderson, C. (2005). Be cool: Natural systems to beat the heat. *Home Power, 108,* 20-25
- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light*. New York: John Wiley & Sons, Inc.

Design Considerations
For Cooling

- Don't block breezes – breezes help keep the home cool
- Plants can decrease cooling requirements by 17-57% (Buckholder & Anderson, 2005; Brown and DeKay, 2001)
- Try and have the tree canopy cover at least 20% of the property
- Shade all air conditioners and paved surfaces - this is very important (South Carolina Energy Office, n.d.; McPherson & Rowntree, 1993)

For Windbreaks

- Plant a dense foundation of evergreens around the home complimented by windbreaks and hedges further out
- Windbreaks can provide 5-15% heat savings (McPherson & Rowntree, 1993)
- Windbreaks have a "wind-shadow" (can block wind for a distance) of 2-4 times their height (Brown & DeKay, 2001)
- Evergreens are best for windbreaks

Photo: A row of north-facing dense shrubs provides a windbreak against cool winter winds while trees on the east and west shade during the summer

Insulation

Introduction

The proper insulation and sealing of a home is arguably the most important strategy in reducing a home's energy requirements. The environmental impacts are large: heating and cooling account for over 50% of North American home energy use (Brown & DeKay, 2001). Leakage and poor insulation is the leading cause energy loss in most homes (Department of Energy, 2008). Improving insulation cuts energy bills and also makes the home more comfortable to live in (Brown & DeKay, 2001).

In general, any home that uses efficient cooling or passive heating must be well insulated (Brown & DeKay, 2001). Passive strategies that require good insulation include: increasing glazing, incorporating thermal mass, evaporative cooling, or any expensive structural change made to the home to cut energy costs. The exception to this rule is shading or other very cheap strategies. Since shading is so effective and cheap it should both be employed on poorly insulated homes.

The best way to insulate a home is during initial construction (or a large renovation). It is expensive and difficult to insulate a home after construction (Department of Energy, 2008). If this cannot be done, applying insulation on the outside of the home in the form of rigid extruded foam is often the cheapest and most effective way to insulate. Incorporating the insulation into the building (ex. straw bale) can also help reduce bridging and reduce material use as well (Magwood et al, 2003).

Design Considerations

- Determine how much insulation is appropriate for your location (see further reading)
- R-values are commonly used for measuring insulation
    - Learn what they mean
    - Be careful of the units being used (Imperial is used the US, but both metric and imperial are used in Canada)
    - Metric R values are called RSI values
- Proper installation is just as important as the insulation type (Department of Energy, 2008)

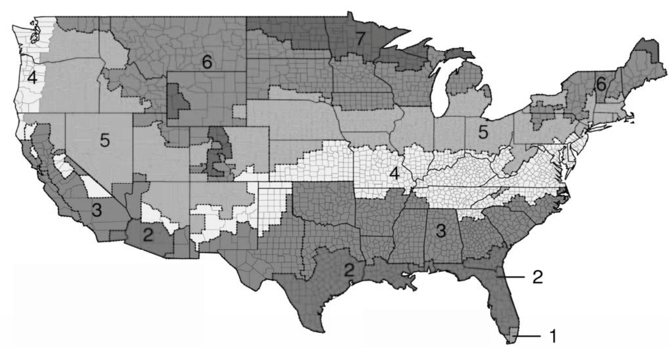


Photo: Insulation zones for the US. Canadian zones can be accurately estimated from this map. All zones colder than 6 have the same insulation values (USDA, 2008).

Further Reading

- United States Department of Energy. (2008). *DOE/CE-0180: Insulation fact sheet.* Retrieved October 13, 2011 from http://www.ornl.gov/sci/roofs+walls/insulation/ins_08.html -This is essential reading and this gives recommendations for insulation levels for the US that can be easily expanded by eye for use in Canada. For areas in Canada far from the US border, use highest recommended levels

Natural Lighting

Introduction

Natural lighting is one of the most efficient ways to reduce electricity use. It takes only a very little amount of daylight to light a room. The trick with natural lighting is to balance the need for light with other needs like passive heating or heat loss (Brown & DeKay, 2001).

In general, rooms that are square are the best candidates for natural lighting. Rooms that are 20 feet deep (away from a light source) or have ceilings that are more than 8 feet high are often (but not always) poor candidates. Fortunately, most residential rooms are under this size.

When making an addition or a large retrofit where rooms will be created and walls moved, try to organize space around natural daylight (Brown & DeKay, 2001). Even rooms that face away from the sun or are shaded by a tree can be lit with natural light.

Remember that windows are not very good at insulating and can cause heat loss in the winter and overheating in the summer. Use only what is needed and consult the Passive heating tool to determine if natural lighting needs are balanced with passive heating needs.

Natural lighting is not limited by access to windows. Solar tubes are excellent choices for rooms in the centre of the home. Solar tubes are made from aluminum and can direct light through the tube by reflection down into a room. See photo for example

Design Considerations

- Increasing the amount of light-coloured surfaces in a room is a cheap way to brighten a room
- This includes paint colour, floor colour, and furniture colour
- Place light coloured surfaces in strategic locations to reflect light
- At low latitudes, 10-20 degrees, over 90% of light can come from the sun, while at 70 degrees about 60% or less can come from the sun (Brown & DeKay, 2001).
- Place North Windows sparingly and place high to allow for deep light penetration (Stein & Reynolds, 2000)

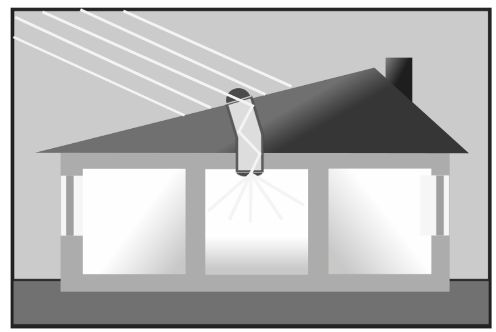


Photo: A solar tube provides light to the middle rooms while windows light the exterior rooms

Further Reading
-Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.
-Herman, C. (2005). Designing with daylight. *Home Power,* volume 109, pp. 40-43.
-Build It Solar's section on Solar and Efficient Lighting. http://www.builditsolar.com/Projects/Lighting/lighting.htm

Outdoor Rooms

Introduction

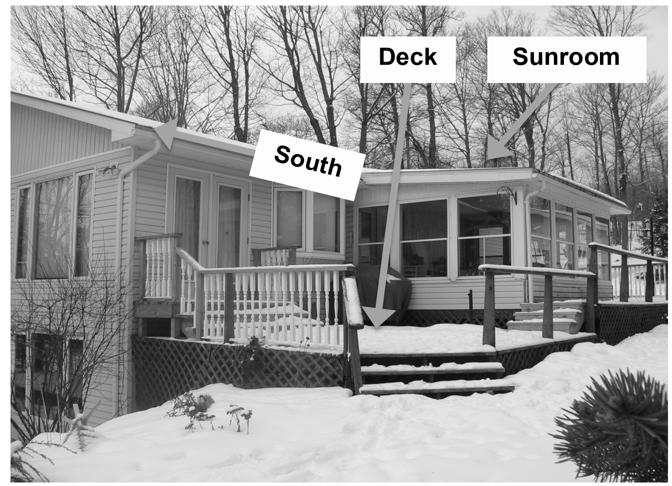
Outdoor rooms, like patios, sunrooms, and porches, can be used as an extension of the indoor space and serve as an additional room. Heated and insulated indoor rooms are expensive to build and heat and need more materials and energy than outdoor rooms. For example, a seating area outdoors can replace an indoor sitting room or living room. Outdoor rooms generally use fewer materials, can connect with nature, and do not need energy for heating or cooling.

Consider an outdoor room instead of an addition. It may mean that it is only usable for 6 months of the year, but compare this with the cost savings and it may become more attractive. If an addition is required, then consider adding an outdoor room to compliment the addition. A strategically placed addition can help make the outdoor room more comfortable by blocking or channeling the wind or shading the sun.

A well-designed outdoor room can be comfortable down to 4^{o}C if it is shielded from the wind and it is in the sunlight and people are dressed accordingly (Brown & DeKay, 2001). In many places in North America outdoor rooms are usable most of the year. The Outdoor Room Design Tool can help determine how to set up an outdoor room. When using the tool, remember you can be creative in thinking of ways to block the wind or shade the sun. There are countless ways to use vines, umbrellas, canopies, and other devices. (Brown & DeKay, 2001)

Further Reading

- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.



Photos: This photo shows two excellent types of outdoor rooms: a sunroom and a deck. The home is oriented north-south (the double doors to the deck face east) and so the deck and sunroom get sun from the south all year. The deck can be used during the warm parts of spring and fall and all summer. The sunroom and home protect the deck from cool winds west and north winds. The sunroom is shaded from the hot sun by its roof and has operable windows to cool it on hot days. On cooler days the windows in the sunroom can then be closed for warmth, like in the early spring and late fall. These rooms are not insulated and are much cheaper than building an insulated and heated addition. This combination of deck and sunroom can be used for the majority of the year.

Passive Solar Heating

Introduction

Passive heating is when the sun is used to heat the home. Windows, sunspaces, and trombe walls can be used to capture the suns heat and reduce or eliminate the need for a furnace. The amount of glazing (glass) determines how much heat can enter the home.

The effectiveness of passive solar depends greatly on three factors: the home's insulation levels, how heat is moved around the home, and how leaky the home is. The home must be well insulated, move air through the home well and be sealed tightly against any air leaks (Brown & DeKay, 2001).

In cold climates choose windows with the best Energy Rating (ER). Positive ERs mean more energy will be saved that lost through the window (CMHC, 1998). The CMHC reading below is essential. Canada is good for passive solar because it is very sunny and despite the cold, many places can get from 1/3 to ½ of their heating needs from the sun (CMHC, 1998).

Since the sun can provide more energy than is needed during the day but not enough at night, thermal mass can be used to store the excess daytime heat and release it at night. Thermal mass is used to moderate temperature through the day and night. Reading the Thermal Mass Primer will help in understanding this.

Design Considerations

- The glazing (glass) in passive solar homes should be 6 to 10% of the heated floor area (CMHC, 1998). For larger areas of glazing, thermal mass should be used to prevent overheating
- Windows should be vertical and face within 30 degrees of due south to get significant amounts sun (Brown & DeKay, 2001; CMHC, 1998)
- East and west windows can also pick up some heat, but more east facing is better than more west facing (CMHC, 1998).
- One big window losses less heat less than multiple small windows (CMHC, 1998).
- For a solar heated home (or largely solar heated), non-south windows should be less than 10-15% of total window area. These windows will loose more heat than they gain(Brown & DeKay, 2001)
- Passive solar heating must be balanced with day lighting. This should be considered on a case-by-case basis

Photo: A passive solar home. Large windows face south to capture the sun's heat (Magwood, 2012)

Further Reading

- Canada Mortgage and Housing Corporation. (1998). *Tap the sun: Passive solar techniques and home designs 2nd Ed.* Ottawa, ON: CMHC
- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.
- Builditsolar.com – look at the passive heating projects for ideas and information

Sunspaces

Introduction

Sunspaces act like greenhouses that are attached to the side of home. The photo shows a typical sunspace attached to a home. They heat up during the day and can provide heat to the home in cool weather (Anderson & Wells, 1981). These spaces can see huge swings in temperature between day and night and can get quite hot, making them great for heating the home. However the extreme heat during the day can make them unusable for other purposes. This can be fixed if the sunspace uses a thermal mass to moderate temperature (Brown & DeKay, 2001). This will make the room useable for other purposes like as a greenhouse or sitting room. In the summer the room must be vented very well or shaded very well. If not, the room will transfer unwanted heat to the home (Brown & DeKay, 2001).

The heat from the space must be moved into the home. In warm climates where home have little insulation the heat simply moves through the lightly insulated wall. In cold climates, this is done with vents, doors or windows and a fan (Brown & DeKay, 2001).

Photo: A home with a typical sunspace that doubles as a green house (Build it Solar, 2011)

Design Considerations

- Locate on south side of home (CMHC, 1998)
- Connect to as many rooms as possible with vents (CMHC, 1998)
- Try not to have them protrude if possible (build into home) (CMHC, 1998)
- Separate sunspace from the main living space with a wall (CMHC, 1998)
- Use a thermostat controlled fan to circulate the air (CMHC, 1998)
- Ratio of thermal mass area to glazed (glass): 3:1 (Brown & DeKay, 2001).
- Vents should be operable and be located at the top and bottom of the space to use natural air convection (CMHC, 1998)

Further Reading
- Canada Mortgage and Housing Corporation. (1998). *Tap the sun: Passive solar techniques and home designs 2nd Ed.* Ottawa, ON: CMHC
- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.
- Builditsolar.com – look at the passive heating projects for ideas and information

Solar Chimney/Trombe Wall

Introduction

A solar chimney or Trombe wall is a solar air heater. They often look like many other types of solar thermal collectors. An example is shown in the photo below. It is positioned on the home either on the roof or on a wall. Trombe walls can be a cheaper alternative to installing new windows for passive heat.

The sun shines through the glass panel heating the air between the glass and wall. The sun also heats the back wall of the collector. The hot air rises and is directed into the home for heat. There is an air inlet/intake at the bottom of the collector that pulls cool air from the floor of the home into the collector. An outlet allows the heated air into the home (Anderson & Wells, 1981). The back of the collector is made of a material that has good thermal mass to absorb the sun's heat (Anderson & Wells, 1981). This heat is stored and allows the collector to work into the night (Anderson & Wells, 1981; Khanal & Chengwang, 2011)

The ultimate goal is to increase airflow in the collector to increase the number of air changes (ACH) that occur. ACH is the number of times the air in a home is replaced, often measured in hours. A good goal is 15 ACH per hour to prevent overheating (Khana & Chengwang, 2011). There are commercial units that can be bought that do not use thermal mass but are quite effective.

Design Considerations

- Performs best when perpendicular to suns rays (Brown & DeKay, 2011)
- Put trombe wall on west for late evening heat in addition to south wall (Stein & Reynolds, 2000)
- Vents are positioned at the top and bottom of the collector. Size Vents as follows (SSF = Solar Saving Fraction):
  - SSF=0-25, make vent 3% of glazing area
  - SSF=25-50, 2%
  - SSF= 50-90, 1%
  - SSF=100, no vents

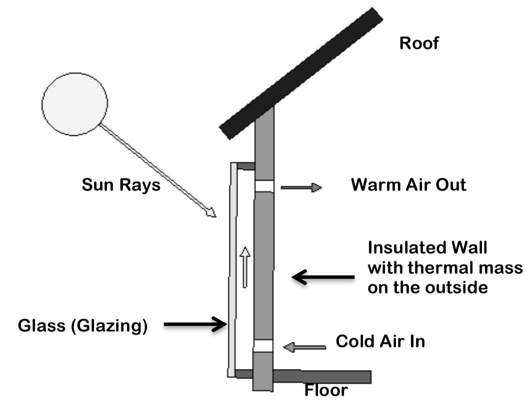


Photo: Diagram of a solar chimney/trombe wall. Cold air from the floor moves in the lower vent, is warmed by the sun, and then exits though the upper vent

Further Reading

- Canada Mortgage and Housing Corporation. (1998). *Tap the sun: Passive solar techniques and home designs 2nd Ed.* Ottawa, ON: CMHC
- Builtitsolar.com – look at the Projects for solar space heating
- Anderson, B. & Wells, M. (1981). *Passive Solar Energy.* Andover: Brick House Publishing Co., Inc.

Standalone Photovoltaic System

Introduction

Photovoltaic (PV) panels turn sunlight into electricity that can then be used in the home or fed back into the electrical grid for profit. When the PV system is not connected to the main electrical grid and only powers the home it is called a *standalone* system. When the PV system is connected to the grid and energy is sold back to the grid it is called a *grid-connected* system (Stein & Reynolds, 2000). This tool focuses on the standalone system. However, if the standalone system does not seem appropriate or is too expensive, a grid-connected system should be considered because they do not need to be as large as standalone systems (Stein & Reynolds, 2000). Some governments have programs in place to help homeowners sell their energy to the grid, such as Ontatio's FIT Program (OPA, 2011).

Standalone PV systems consist of several main components: PV (solar) panels, a panel mounting system, batteries, and converter modules that control the electricity (Stein & Reynolds). The main issue with standalone systems is that they only produce power when the sun shines. Unfortunately, that is usually during the day when people are at work and there is less need for electricity. There can also be cloudy periods where the panels will not produce enough power. To overcome these problems batteries are needed to store power for use in the evenings and on cloudy days (Stein & Reynolds).

Standalone systems do have many good qualities. They have a long lifespan and they are reliable and easy to maintain (Kalogirou, 2009). They work well in hot and cold climates so harsh winters are not a problem (Kalogirou, 2009).

Design Considerations

- Most system components will last for about 20 years or more, except for the batteries that have a lifespan of 5 to 10 years (Stein & Reynolds).
- You need to know the home's electricity use and the sunlight available (Stein & Reynolds, 2000).
- For cost reasons, the home needs to be very energy efficient. This will cut down on the size of the system and the costs (Stein & Reynolds, 2000).
- PV systems are modular so you can add more panels as you can afford them
- Shadows from trees or even chimneys as well as the direction of the panels can significantly affect performance (Stein & Reynolds, 2000).
- There are many companies who specialize in PV systems. They will be needed for a detailed sizing and costing of the system

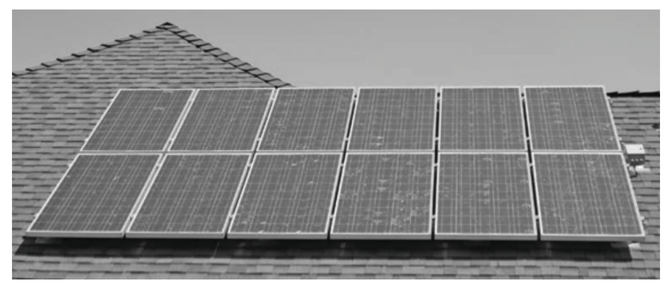


Photo: Roof mounted Photovoltaic system (Marken & Sanchez, 2008)

Further Reading

- Natural Resources Canada. (2002). *Photovoltaic systems: A buyer's guide.* Ottawa, ON: Natural Resources Canada. (Available online)
- Canada Mortgage and Housing Corporation [CMHC]. (2005). *About your house: Photovoltaics (PV).* Ottawa, ON: CMHC (Available online)

Roof Colour and Type

Introduction

The colour of a roof can affect indoor temperature. Dark coloured roofs absorb heat while light coloured roofs reflect heat. These two basic principles can be used to help reduce indoor temperatures and cooling costs.

In hot climates, a near white roof can help significantly lower indoor temperature. A light coloured roof is about the same as increasing insulation by 50% when compared to a dark roof (Suehrcke et al, 2008). Light roofs cut cooling costs in two ways. First they reduce heat gain through the roof by 13-22% in poorly insulated homes, and 7-12% in newer homes (Brown & DeKay, 2001). Secondly, they reduce temperatures around the home (dark roofs get extremely hot and heat the air around the home) (Brown & DeKay). Exact savings are hard to determine, but are usually positive (Suehrcke et al, 2008).

At night a dark roof can release heat better than a light roof helping to cool the home. Thus an alternative cooling method may be needed in the evening such as a whole house fan or evaporative cooling.

Design Considerations

- White tile or metal roofs are very good at reflecting heat
- Asphalt shingles (even white ones) can absorb large amounts of heat
- In warm climates, light roofs are superior in virtually all situations
- In cool climates, there is often a net benefit for a light roof but not always
- The Light Roof Savings Tool can help determine if a light roof is a good idea in your climate

Photo: Suburban homes with white metal roofs. This will keep the homes and surrounding air cooler (Buczynski, 2010)

Further Reading
- *A white roof is a cool roof* by Beth Buczynski on Green Upgrader http://greenupgrader.com/10549/a-white-roof-is-a-cool-roof-how-to-reduce-home-energy-use-by-20/
- *Cool Roofing Information for Home and Building Owners* by the Cool Roof Rating Council http://www.coolroofs.org/HomeandBuildingOwnersInfo.html#Benefitsofacoolroof
- A more technical document but also a good resource is *Guide for estimating differences in building heating and cooling energy due to changes in solar reflectance of a low-sloped roof* by the Oak Ridge National Laboratory.

Shading and Overhangs

Introduction

While the sun can provide wonderful heat in the winter, it can also cause unwanted heating in the summer. To stop unwanted heat, the home needs to block the sun at certain times of the year. Blinds and overhangs are simple and remarkably effective at doing this (Brown & DeKay 2001).

Blinds can be used on the outside or inside of the home. Retractable blinds on the outside are best because they stop the sun's heat before it enters the home. Unfortunately they are subject to wear and tear from weather (Buckholder & Anderson, 2005; Brown and Dekay, 2001). Overhangs and awnings can also be used. They can be static and unmoving or can be retractable and adjustable.

The sun moves in predictable patterns through the sky: high in summer, low in the winter. Static overhangs take advantage of these patterns by blocking summer sun when it is high but letting in the low winter sun. However, they are designed based on average heating and cooling needs and tend to block sun in the months of April and September when heating may be wanted. This can be fixed by making the overhangs adjustable (Brown & DeKay, 2001).

There are multiple types of blinds and overhangs. Thorough research should be done to determine the best blinds or overhangs for the situation. The Overhang Design Tool can help determine the right size of awning.

Design Considerations

- Blinds come in many different styles: insulated vs non-insulated, automatic vs manual, outside vs inside, opaque vs translucent etc.
- Using blinds at night can reduce heat lost through radiation (your warm home emits heat through radiation)
    - This must be used carefully because blinds on the inside can hold air against the window, cooling it, then the air falls to the floor pulling in warm air from the top creating a cooling loop

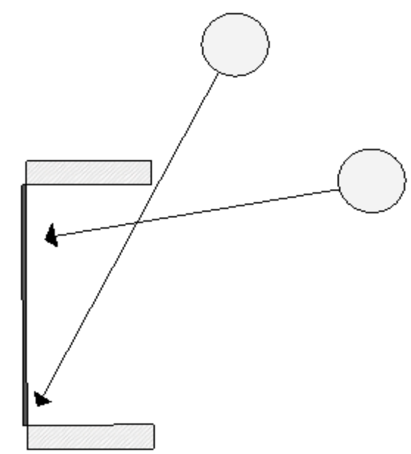


Photo: The window overhang blocks the high summer sun to keep the home cool while admitting the low winter sun to help warm the home

Further Reading

- Herman, C. (2005). Designing with daylight. *Home Power* volume 109, pp. 40-43.
- Brown, G.Z., & DeKay, M. (2001). *Sun, wind & light.* New York: John Wiley & Sons, Inc.

Solar Water Heating

Introduction

Using solar energy to heat water is one of the most economical options for reducing energy costs (Brown & DeKay, 2001). Solar hot water systems are reliable and simple and can easily provide up to 100% of a home's summer hot water needs and substantial amounts of the winter needs as well (Brown & DeKay, 2001). They work by using panels that capture the sun's heat that then warms a fluid, often called a *working fluid* (Kalogirou, 2009). This hot working fluid is then pumped inside the home where the heat from the fluid is transferred to water that is stored in a hot water tank ready for use (Kalogirou, 2009). The whole system is automatically controlled by a thermostat (Kalogirou, 2009). The main components of the system are: a solar collector array, heat transfer system and a hot water tank (Kalogirou, 2009). The most frequently used collectors are *flat-plate* collectors as shown in the photo. They consist of copper tubes running through a rectangular glass plate where the working fluid in the tubes is heated by the sun. The other type of collector that is often used is an *evacuated tube* collector (Brown & DeKay, 2001). These collectors can reach higher temperatures than flat plate collectors but are more expensive. Both types of collectors are mounted in the sun (often on a roof) and are stationary (don't track the sun) (Kalogirou, 2009). There are several types of systems that differ by the way they move the working fluid (gravity or pump), the type of working fluid (water or freeze resistant fluid), among other differences (Kalogirou, 2009; Brown & DeKay, 2001). A professional will bee needed to design the system.

Design Considerations

- Panels should face roughly south
- Shading can pose big problems (trees, other homes, etc.)
- Panels can provide 100% of the winter hot water but it can be costly
- Solar hot water is often combined with another type of water heater
- Combine installation with other renovations to cut costs
- Panels can be roof or ground mounted depending on space and shadows
- Systems can work in hot and cold climates

Photo: Roof-mounted, flat panel solar collectors used for heating water (Olsen, 2001)

Further Reading

- Olsen, K. (2001). Solar hot water: A primer. *Home Power,* volume 84, 44-52.
- Builditsolar.com – look at the solar water heating projects for ideas and information
- Natural Resources Canada. (2003). *Water heating systems: A buyer's guide.* Ottawa, ON: Natural Resources Canada. (Available online)

Straw Bale Construction

Introduction

Straw bale construction has been around for over a century. It originated in Nebraska where a lack of lumber prompted the inventive use of straw (Magwood et al., 2005). Straw bale homes are constructed by laying bales down like bricks and plastering both the inside and outside with a breathable plaster (Vardy & MacDougall, 2006: Magwood et al, 2005). Straw bale construction is gaining popularity all over North America and has been accepted as an excellent and sustainable building material.

Straw can often be sourced locally as a by-product of farming. It is cheap, readily renewable, has an excellent insulation value and cuts down on wood use. It must be straw, not hay.

If designed properly with passive solar and passive cooling, straw can reduce or eliminate the need for a furnace or air-conditioner because the wall has an R-value of at least R-30. Straw bale construction is a great choice for both hot and cold climates (Magwood et al., 2005).

There are often concerns about mice, fire, rot and moisture. These are all understandable but unfounded concerns. Straw bale homes provide unsuitable habitat for mice and rodents who would rather live in the batt insulation of a conventional home (Magwood at al. 2005). Straw bales have been shown to exceed the fire safety requirements for residential homes (Omega Point Laboratories, 2000; Development Centre for Appropriate Technologies, 1993). Like any home, moisture can be a problem if improperly designed. Research shows that moisture is not an issue for most of North America except the American south east, where more research is needed to draw conclusions (Carfrae, 2011).

Design Considerations

- There are two main types of straw bale construction: *non-load-bearing* and *load bearing*.
  - The non-load-bearing method uses a wood frame (conventional stud-frame, timber frame, etc.) as structural wall system and the bales are used only as insulation (Magwood, et al., 2005). This method requires the same amount of wood as a conventional wood-frame home.
  - A load-bearing straw bale home uses the plastered bales as the main structural wall system (Magwood et al., 2005).
- Load-bearing construction exceeds building code requirements for wall strength (Vardy and MacDougall, 2006)
- Straw bale constrctuon should be chosen where straw is readily available and the climate is not excessively humid (eg Florida). (Magwood et al., 2005).

Photo: Straw bale home using passive solar techniques (Magwood, 2012)

Further Reading

- *More straw bale building: A complete guide to designing and building with straw.* (2005) By Chris Magwood, Peter Mack and Tina Therrien
- Look at http://www.greenhomebuilding.com/ under the straw bale section. This site contains much information but also a list of good resources

Adobe

Introduction

Adobe is a building method that uses sunbaked bricks made out of clay called adobes. Adobes can be made locally where the soil is of the right composition. When constructing the home, the bricks are stacked the same as normal bricks then plastered on the outside and inside similar to stucco. Adobe bricks can in be bought in some places or made on-site. They are labour intensive to make since they are crafted by hand and cured in the sun rather than mass-produced (Moquin, 2000). However, their environmental impact is miniscule compared to conventional bricks. Brick for brick, it takes 1% of the energy to make an adobe brick as it does to make an equivalent fired brick or Portland cement brick (Moquin, 2000). Adobe can replace more than 50% of the wood required to build a conventional home (Moquin, 2000).

They are extremely strong buildings, easily meeting building codes. They are inherently fire and rodent proof (Moquin, 2000). Like any other building, adobe should be protected from moisture (Moquin, 2000). Raised foundations can help stop moisture from the ground from soaking into the bricks. In humid climates, adobe can actually help control humidity in the home by absorbing the humidity into the dry bricks. Adobe gets stronger when it absorbs moisture hitting peak strength at 60% relative humidity (Moquin, 2000; Minke, 2006). Since adobe is made of earth, it has excellent thermal mass characteristics and can help moderate temperature in places where it gets very hot or cold at certain times of the day (Moquin, 2000).

Design Considerations

- Walls of 20-30cm (8-12in) provide optimal thermal mass (Moquin, 2000).
- In places where the average daily temperature is in the comfort zone (18°C to 25°C) no insulation will be needed because the thermal mass will moderate temperature (Moquin, 2000).
- In cold or hot climates insulation will be needed since adobe buildings have an R-value of only about 20.
- Place insulation on the outside of the building, leaving the wall exposed on the inside for thermal mass (Moquin, 2000).
- Use overhangs to protect home in rainy areas (Moquin, 2000).
- Moisture in the wall during freeze-thaw cycles can harm wall (King, 2000).

Photo: An adobe home in the traditional southwest style (Mescal Highlands, n.d.)

Further Reading

- Look at http://www.greenhomebuilding.com/ under the adobe section. This site contains much information but also a list of good resources
- *Alternative construction: Contemporary natural building methods* Edited by Elizabeth & Adams published byJohn Wiley & Sons, Inc. is a good resource for learning the basics of adobe and rammed earth.

Rammed Earth

Introduction

Rammed earth construction is an earth-based construction technique like adobe. It has been used for centuries in many different cultures across the world and has proven itself an excellent building material in all climates. To make a reamed earth wall, soil is poured into forms similar to the forms used for building concrete walls and then tamped down (Minke, 2006). This is done in layers, slowly building the wall up. The wall needs no plaster on the outside and the walls often show the different coloured layers of the soil in an appealing way. The soil used must be of the right composition and contain virtually no organic matter (Minke, 2006). This building technique is labour intensive but the building material can be sourced from local soil and when demolished, the walls simply become earth again (Minke, 2006).

Since rammed earth is made of soil, it has very similar characteristics to adobe. It has excellent thermal mass characteristics and can help moderate temperature in places where it gets very hot or cold at certain times of the day (Moquin, 2000). It can perform well in hot and cold climates with a layer of rigid extruded foam insulation built into the middle of the wall. It must be protected from moisture in the same way as adobe but can also moderate humidity like adobe (Minke, 2006).

Design Considerations

- Rammed earth can be stabilized with small amounts of cement (Minke, 2006)
- Rammed earth walls can be stronger than concrete walls (Minke, 2006).
- Walls of 20-30cm (8-12in) provide optimal thermal mass (Moquin, 2000).
- In places where the average daily temperature is in the comfort zone (18°C to 25°C) no insulation will be needed because the thermal mass will moderate temperature (Moquin, 2000).
- In cold or hot climates insulation will be needed since rammed earth has low insulation values
- Place insulation in the middle of the wall during construction leaving the beautiful walls exposed for thermal mass (Moquin, 2000).
- Use overhangs to protect home in rainy areas (Moquin, 2000).
- Moisture in the wall during freeze-thaw cycles can harm wall (King, 2000).

Photo: A portion of a rammed earth home. Note the layers on the wall (Schooly, 2008)

Further Reading

- Look at http://www.greenhomebuilding.com/ under the adobe section. This site contains much information but also a list of good resources
- *Alternative construction: Contemporary natural building methods* Edited by Elizabeth & Adams published byJohn Wiley & Sons, Inc. is a good resource for learning the basics of adobe and rammed earth.

APPENDIX F – REDUCING THE HOME'S ENVIRONMENTAL IMPACT: DESIGN TOOLS AND CALCULATIONS

F.1 NOMENCLATURE FOR TACTIC DESIGN

$C_{cool}, C_{heat} - unit\ cooling\ and\ heating\ energy\ cost\ respectively\ (\$/unit)$
$\Delta C_{cool}, \Delta C_{heat} - change\ in\ total\ cooling\ and\ heating\ costs\ \ (\$)$
$C_{save} - total\ amount\ of\ money\ saved\ by\ \ changing\ roof\ colour\ (\$)$
$COP_{AC} - Coefficient\ of\ performance\ for\ cooling\ system$
$e_{furnace} - furnace\ efficiency\ (\%)$
$A_{roof,total} - total\ roof\ area\ (m^2)$
$I_{day} - Average\ daily\ insolation\ (kj/m^2/day)$
$\Delta G_{ref} - roof\ reflectance\ change\ (fraction\ from\ 0\ to\ 1)$
$f_{ce}, f_{he} - cooling\ and\ heating\ factors\ respectively$

$T_i - Desired\ water\ temperature\ delivered\ from\ solar\ panel\ (K)$
$T_a - Ambient\ air\ temperature\ for\ the\ month\ in\ questions$
$T_g - ground\ water\ temperature\ (K)$
$e_{panel} - panel\ efficiency\ (\%)$
$I_o - clear - day\ insolation\ on\ a\ 40^o\ surface\ (kW)$
$\dot{m}_{water} - daily\ water\ use\ (L/day)$
$f_s - \%\ of\ hot\ water\ to\ come\ from\ collectors$
$I_t - daily\ clear - day\ insolation\ on\ a\ 40^o\ surface\ (kJ)$
$q_{hw} - energy\ needed\ to\ heat\ water\ per\ day\ (kJ)$
$c_{p,water} - specific\ heat\ capacity\ of\ water\ (kj/kgK)$
$A_c - solar\ hot\ water\ collector\ area\ (m^2)$

$h_w - window\ height\ (m)$
$l_{oh} - overhang\ length\ (m)$
$f_{oh} - overhang\ factor\ \ (dimensionless)$

$AC_{app,load} - appliance\ load\ from\ single\ AC\ appliance\ (Wh)$
$AC_{total} - total\ AC\ appliance\ load\ from\ all\ AC\ appliances\ (Wh)$
$AC_{adjut} - total\ AC\ appliance\ load\ derated\ due\ to\ DC\ conversion\ (Wh)$
$DC_{app,load} - appliance\ load\ from\ single\ DC\ appliance\ (Wh)$
$DC_{total} - total\ DC\ appliance\ load\ from\ all\ DC\ appliances\ (Wh)$
$f_{AC} - AC\ to\ DC\ conversion\ derating\ factor$
$TL - total\ electrical\ house\ load\ (kwh/day)$
$PL - Peak\ load\ (kw)$
$I - insolation\ (kwh/m^2/day)$
$V_b - electrical\ voltage\ of\ battery\ storage\ system\ (V)$
$f_d - battery\ system\ discharge\ derating\ factor\ (dimensionless)$

$f_t - battery\ system\ temperature\ derating\ factor$ (dimensionless)
$D_{dark} - number\ of\ days\ without\ sun\ to\ charge\ PV\ batteries$
$BS - battery\ system\ size\ (AH)$

$GRF - ratio\ of\ current\ glazing\ to\ heated\ floor\ area\ (m^2/m^2)$
$A_{g,current} - current\ amount\ of\ south\ facing\ glazing\ (m^2)$
$A_{heat\ floor} - the\ home's\ total\ heated\ floor\ area\ (m^2)$
$A_{g,target} - south\ facing\ glazing\ area\ needed\ to\ meet\ SSF_{target}\ (m^2)$
$SSF_{target} - target\ SSF\ for\ local\ climate\ (\%)$
$SSF_{base} - the\ SSF\ of\ the\ base\ or\ reference\ home\ (\%)$
$SSF_{current} - the\ home's\ current\ SSF\ (\%)$
$SFF_{proposed} - proposed\ SSF\ for\ home\ after\ retrofit\ (\%)$

$q_w - window\ heat\ gain\ (W)$
$q_d - door\ heat\ gain\ (W)$
$q_{wa} - wall\ heat\ gain\ (W)$
$q_r - roof\ heat\ gain\ (W)$
$q_i - infiltration\ heat\ gain\ (W)$
$q_l - lighting\ heat\ gain\ (W)$
$q_a - appliance\ heat\ gain\ (W)$
$q_o - occupant\ heat\ gain (W)$
$q_s - sensible\ heat\ gain\ (W)$
$q_{la} - latent\ heat\ gain\ (W)$
$Q_{cl} - daily\ cooling\ load\ (J)$
$F_w - window\ factor\ (dimensionless)$
$F_i - infiltration\ factor\ (dimensionless)$
$F_l - bulb\ factor\ (W/W)$
$U_d - door\ heat\ transfer\ coefficient\ (W/m^2K)$
$U_{wa} - wall\ heat\ transfer\ coefficient\ (W/m^2K)$
$U_r - roof\ heat\ transfer\ coefficient\ (W/m^2K)$
$DETD - design\ equivalent\ temperature\ difference\ (K)$
$A_d - total\ outside\ door\ area\ (m^2)$
$A_{wa} - total\ outside\ wall\ area\ (m^2)$
$A_r - total\ roof\ area\ (m^2)$

$q_v - ventilation\ heat\ removal\ rate\ (W)$
$\dot{v} - air\ volume\ flow\ rate\ through\ home (m^3/s)$
$\dot{v_w} - wind\ volume\ flow\ rate\ through\ home (m^3/s)$
$\dot{v_s} - stack\ air\ volume\ flow\ rate\ (m^3/s)$
$\dot{v_f} - fan\ air\ volume\ flow\ rate\ (m^3/s)$
$\rho_{air} - density\ of\ air\ (kg/m^3)$
$c_{p,air} - specific\ heat\ capacity\ of\ air\ (kJ/kg \cdot K)$

$T_{in} - indoor\ air\ temperature\ (K)$
$T_{out} - outdoor\ air\ temperature\ (K)$
$t_f - heat\ removal/flush\ time\ (s)$
$C_v - wind\ effectiveness\ factor$
$v_w - wind\ velocity\ (m/s)$
$k - discharge\ coefficient\ (dimensionless)$
$g - gravity\ (m/s^2)$
$h - height\ from\ inlet\ to\ outlet\ (m)$
$A_{inlet} - inlet\ area\ (m^2)$

$c_{mass} - heat\ capacity\ of\ thermal\ mass\ (kJ/K)$
$c_{p,mass} - specific\ heat\ capacity\ of\ thermal\ mass\ (kJ/kg \cdot K)$
$v_{mass} - thermal\ mass\ volume\ (m^3)$
$\rho_{mass} - thermal\ mass\ density\ (kg/m^3)$
$q_{mass,cool} - cooling\ capacity\ of\ thermal\ mass\ measured\ hourly\ (kJ)$
$q_{mass,total} - total\ nightly\ cooling\ capacity\ of\ thermal\ mass\ (kJ)$
$q_{supp} - total\ nightly\ thermal\ mass\ cooling\ from\ other\ mass\ in\ home\ (kJ)$
$q_{total} - total\ nightly\ thermal\ mass\ cooling\ from\ all\ sources\ (kJ)$
$Q_{mass,max} - maximum\ cooling\ rate\ reached\ by\ thermal\ mass\ (kW)$
$T_{mass,prev\ hour} - temperature\ of\ thermal\ mass\ from\ previous\ hour\ (K)$
$T_{mass} - current\ temperature\ of\ thermal\ mass\ (K)$
$T_{mass,final} - final\ temperature\ of\ thermal\ mass\ (K)$
$T_{night,low} - nightly\ low\ (K)$
$T_{test} - temperature\ test\ to\ check\ if\ thermal\ mass\ is\ adequate\ (K)$
$k_s - surface\ conductance\ of\ thermal\ mass\ (W/m^2K)$
$A_{mass} - exposed\ surface\ area\ of\ thermal\ mass\ (m^3)$
$\dot{v}_{air,cooling} - volume\ flow\ rate\ of\ air\ over\ thermal\ mass\ (m^3/s)$
$v_{home} - volume\ of\ home\ (m^3)$
$ACH - air\ changes\ per\ hour$

$R_{e\ max} - maximum\ reliability\ of\ rain\ barrel\ (\%)$
$R_e - selected\ reliability\ of\ rain\ barrel\ (\%)$
$A_{roof} - rain\ capture\ area, usually\ the\ projected\ area\ of\ the\ roof\ (m^2)$
$B - barrel\ size\ (L)$
$\phi - runoff\ coefficient$
$\psi - distribution\ parameter\ of\ intervent\ time\ (1/h)$
$\zeta - distribution\ parameter\ of\ rainfall\ event\ volume\ (1/mm)$
$G - water\ use\ rate\ (L/day)$
$v_{ff} - first\ flush\ volume\ to\ be\ diverted\ (mm)$
$R_p - soakaway\ pit\ reliability\ (\%)$
$R_o - yard\ pond\ reliability\ (\%)$
$v_{rain} - rainfall\ volume\ (mm)$

$v_{water} - water\ volume\ to\ accommodate\ (m^3)$
$v_{pit} - soakaway\ put\ volume\ (m^3)$
$v_{pond} - yard\ pond\ volume\ (m^3)$
$p_{fill} - soakaway\ pit\ fill\ porosity\ (\%)$
$\dot{n} - infiltration\ rate\ (mm/h)$
$l_{pit}; w_{pit}; d_{pit} - soakaway\ pit\ length\ width\ and\ depth\ respectively\ (m)$
$l_{pond}; w_{pond}; d_{pond} - yard\ pond\ length\ width\ and\ depth\ respectively\ (m)$
$d_{min} - soakaway\ pit\ minimum\ depth\ (m)$
$T_{drain} - water\ drain\ time\ (h)$

F.2 White Roof Savings Calculator

Adapted from Griggs, Sharp, & MacDonald (1989).

Note that for 'unit fuel cost' has not been defined in specific units since this deals with heating and there are many different types of heating fuels and measurements of those fuels.

Estimate unit cooling energy costs:

$$C_{cool} = \frac{Unit\ Fuel\ Cost\ (\$/energy\ unit)}{COP_{AC}}\ ;\ (\$)$$

Estimate unit cooling energy costs:

$$C_{heat} = \frac{Unit\ Fuel\ Cost\ (\$/energy\ unit)}{e_{furnace}}\ ;\ (\$)$$

Estimate the reduction in cooling cost:

$$\Delta C_{cool} = I_{day} A_{roof,total} \Delta G_{ref} f_{ce}\ ;\ (\$)$$

Estimate increase in heating cost:

$$\Delta C_{heat} = I_{day} A_{roof,total} \Delta G_{ref} f_{he}\ ;\ (\$)$$

Estimate total savings:

$$C_{save=} \Delta C_{cool} - \Delta C_{heat}\ ;\ (\$)$$

F.3 Solar Hot Water Sizing and Design

Adapted from Stein and Reynolds (2000) and Natural Resources Canada (2003).

Assumptions:

- The storage temperature of the hot water is the same as the desired water temperature delivered from the solar panels.

Panel output is estimated month by month, thus panel efficiency is estimated for each month. Efficiency curves for panels are as follows:

Panel Type	**Efficiency Curve (%)**
Unglazed, Flat Plate, Flat Black	$e = -400x + 90$
Single Glazed, Flat Plate, Flat Black	$e = -167x + 72$
Double Glazed, Flat Plate, Flat Black	$e = -86x + 70$
Single Glazed, Flat Plate, Black Chrome, Selective Surface	$e = -72x + 74$
Single Glazed, Evaporative Tube, Concentric Selective Absorber	$e = 48$

Where $x = \frac{T_i - T_a}{I_o}$; (K/kW)

Determine energy needed to heat water for daily needs:

$$q_{hw} = \dot{m}_{water} c_{p,water} \left(T_i - T_g\right) \; ; \; (kJ)$$

Determine solar collector area needed:

$$A_c = \frac{q_{hw} * f_s}{I_t * e_{panel}} \; ; \; (m^2)$$

F.4 OVERHANG SIZING

Adapted from Brown and DeKay (2001).

Determine overhang length based on window height and location:

$$l_{oh} = h_w * f_{oh}; \ \ (m)$$

Where f_{oh} is the overhang factor determined by the locations latitude and the desired shading months.

F.5 PHOTOVOLTAIC SYSTEM SIZING

Adapted from Natural Resources Canada (2001) and Gromdzik et al (2011).

Assumptions:

- 90% battery charge regulator efficiency
- 85% battery efficiency
- 90% AC to DC converter efficiency
- 50% discharge depth of battery
- Batteries stored at 25°C
- Radiation values are average and may differ year to year
- Panels are south facing and tilted at latitude angle

Find daily AC loads for individual appliances:

$$AC_{app,load} = appliace\ wattage * hours\ used/day * \#\ appliances\ \ ; \ \ (Wh)$$

Find total AC load:

$$AC_{total} = \sum AC_{app,load} \ \ ; \ \ (Wh)$$

AC load needs to be converted to DC. Total adjusted load calculated using a derating factor since PV panels deliver DC, not AC current:

$$AC_{adjust} = AC_{total}/f_{AC} \ \ ; \ \ (Wh)$$

Where $f_{AC} = 0.9$.

Calculate DC loads:

$$DC_{app,load} = appliace\ wattage * hours\ used/day * \#\ appliances\ \ ;\ \ (Wh)$$

Calculate total DC load:

$$DC_{total} = \sum DC_{app,load}\ ;\ (Wh)$$

Calculate total house load per day:

$$TL = AC_{adjust} + DC_{total}\ \ ;\ \ (Wh)$$

Calculate Peak Load (convert TL from Wh to kWh):

$$PL = \frac{TL}{I \Big/ \frac{1kwh}{m^2}}\ \ ;\ \ (kW)$$

Where the $1kwh/m^2$ is the intensity of light used to test PV panels.

Calculate the number of panels needed:

$$\#\ panels = \frac{PL}{panel\ output\ rating\ (kw)}$$

Size the battery system:

$$BS = \frac{D_{dark}\left[\frac{PL}{V_b}\right] * f_d}{f_t}\ \ ;\ \ (Ah)$$

Where the battery size, V_b, is commonly 24 volts and $f_d = 1.2$ and $f_t = 0.85$

F.6 PASSIVE SOLAR HEATING

Adapted from Brown and DeKay (2001).

Determine ratio of current glazing to heated floor area:

$$GFR = \frac{A_{g,current}}{A_{heat\ floor}} \ ; \ \left(\frac{m^2}{m^2}\right)$$

The charts given in Brown & DeKay (2001) are Cartesian plots with linear curves showing the Solar Saving Fraction (SSF) vs. the GFR. Using simple linear extrapolation and the general equation ($y = mx + b$) the equations of the curves can be found and thus the current SSF, $SSF_{current}$. This must be done for each instance, thus curves are calculated on a case by case basis. Filling in the base equation:

$$SSF = SSF_{slope}GFR + SSF_{base} \ ; \ (\%)$$

Brown and DeKay propose a target SSF, SSF_{target}. Using SSF_{target}, the amount of glazing needed to meet that target can be found by:

$$A_{g,target} = \frac{(SSF_{target} - SSF_{base})A_{heat\ floor}}{SSF_{slope}} \ ; \ (m^2)$$

Alternatively, other proposed values of SSF, $SSF_{proposed}$ can be used in place of SSF_{target} to evaluate the effect of different SSFs. These proposed SSFs can be economically evaluated to estimate percent energy saved by increasing the amount of glazing and thus the SSF:

$$\% \ energy\ savings = SSF_{proposed} - SSF_{current}$$

Thermal mass is needed if the SSF of the home is within the target range to avoid over heating. Brown and DeKay (2001) give curves that can be used to estimate the amount of thermal mass needed based on various types of thermal mass. These were simply added into the tool.

F.7 EFFICIENT COOLING SIZING AND DESIGN

Adapted from Stein and Reynolds (2000).

F.7.1 Calculating Heat Gains for a Home

Assumptions:

- Heat gains will only occur during the day from 7am to 9pm

Calculate heat gains (all gains in W):

Window gain:	$q_w = A_w F_w$
Door gain:	$q_d = A_d U_d DETD$
Wall gain:	$q_{wa} = A_{wa} U_{wa} DETD$
Roof gain:	$q_r = A_r U_r DETD$
Infiltration gain:	$q_i = (A_r + A_{wa}) * F_i$
Artificial lighting gains:	$q_l = \#bulbs * bulb\ wattage * F_l$
Average appliance gain:	$q_a = 410W$
Average occupant gain:	$q_o = \#occupants * 134.6W/occupant$

Calculate sensible and latent heat gains:

Total sensible gain:	$q_s = q_w + q_d + q_{wa} + q_r + q_i + q_l + q_a + q_o$
Total latent gain:	$q_{la} = q_s * 20\%$

Estimate total daily cooling load assuming heat is gained from 7am to 9pm:

$$Q_{cl} = q_{s*} q_{la} * 14h * 3600s/h \ ; \ (J)$$

F.7.2 Ventilation Calculations (heat removal)

Adapted from Stein and Reynolds (2000).

Base equation for heat removal rate:

$$q_v = \dot{v} \rho_{air} c_{p,air} (T_{in} - T_{out}) \ ; \ (kW)$$

Flush time (time to remove heat):

$$t_f = \frac{Q_{cl}}{q_v} \ ; \ (s)$$

Estimate volume flow rate of air for wind through a window, a fan, a stack:

- Volume flow rate when using wind through window:

$$\dot{v}_w = C_v A_{inlet} v \ ; \ (m^3/s)$$

$$C_v = 0.55\ for\ wind\ \perp to\ window, 0.3\ for\ wind\ 45^o to\ window$$

- Volume flow rate when using fan, use rated fan volume flow rate:

$$\dot{v_f}\ ;\ (m^3)$$

- Volume flow rate for stack ventilation:

$$\dot{v_s} = 60kA_{inlet}\sqrt{gh\frac{T_{in}-T_{out}}{T_{in}}}\ ;\ (m^3/s)$$

F.7.3 Thermal Mass for Cooling Sizing

Assumptions:

- Daily high occurs at 2pm and is the design temperature found with the Cooling Strategy Selection Chart
- Daily high remains constant until 5pm at which time it begins to cool
- After 5pm the temperature cools linearly to the local average low what occurs at 2am and remains constant until 4am at which time temperature increases linearly to the daily high at 2pm

Step 1 – calculate the temperature profile (in ^oC) using the stated assumptions

Step 2 – calculate the daily heat gain using method in Section A.F.7.1

Step 3 – Calculate volume of thermal mass to be used (m^3). Estimate the area (m^2) and thickness (m). This is an iterative process. Select any amount of thermal mass to start.

Step 4 – Calculate heat capacity of thermal mass:

$$c_{mass} = c_{p,mass} * \rho_{mass} * v_{mass}\ ;\ (kJ/K)$$

Step 5 – Calculate surface area (m^2) cooling (area of exposed mass)

Step 6, 7, & 8 – Estimate the initial temperature of the mass (~27^{o}C suggested). Calculate the cooling capacity of the mass and the temperature of the mass, hour by hour over the evening. Continue until the mass is no longer becoming cooler due to rising outdoor temperature:

$$q_{mass,cool} = \left(T_{mass,prev\ hour-}\ T_{out}\right)A_{mass}k_s \ \ ; \ \ \text{(kJ)}$$

$$T_{mass} = T_{mass,prev\ hour} - \frac{q_{mass,cool}}{c_{mass}} \ ; \ \ ({}^{o}C)$$

Step 9 – Calculate the total cooling capacity of the mass by summing the cooling capacity if the mass for each hour over the night:

$$q_{mass,total} = \sum q_{mass,cool} \ ; \ \ (kJ)$$

Step 10 – Test the final mass temperature to see if the thermal mass is distributed properly:

$$T_{test} = T_{mass,final} - T_{night,low} \ ; \ \ ({}^{o}C)$$

If T_{test} is greater than 4°C (the final mass temperature is 4°C greater than the nightly low) the mass needs to be redistributed, often made thinner. Go back to Step 3.

Step 11 – Calculate the supplementary cooling of the thermal mass from the rest of the home (furniture, walls, etc):

$$q_{supp} = q_{mass,total} * 25\% \ ; \ \ (kJ)$$

Step 12 – Calculate total cooling capacity of all thermal mass:

$$q_{total} = q_{mass,total} + q_{supp} \ ; \ \ (kJ)$$

Step 13 – Calculate the airflow needed to cool the mass:

$$\dot{v}_{air,cooling} = \frac{Q_{max,mass}}{1.2 * \left(T_{mass,final} - T_{out}\right)} \ ; \ \ (m^3/s)$$

where $\dot{q}_{max,mass}$ is the maximum cooling rate achieved by the mass, $T_{mass,final}$ is the final mass temperature and T_{out} is the outdoor temperature at the time of the maximum cooling rate. Air changes per hour required can be found by:

$$ACH = \frac{\dot{v}_{air,cooling}}{v_{home}}$$

F.8 Rain Barrel Sizing

Adapted from Guo and Baetz (2007).

Calculate maximum reliability of barrel based on the location, capture area and use rate:

$$R_{e\,max} = \frac{A_{roof}\phi\psi}{A_{roof}\phi\psi + \zeta G} * e^{-\zeta v_{ff}} \;\; ; \;\; (\%)$$

Calculate the size of the barrel making sure the selected reliability is less than the maximum reliability:

$$B = \frac{A_{roof}\phi G}{\zeta G + A_{roof}\phi\psi} \ln\left[\frac{A_{roof}\phi\psi e^{-\zeta v_{ff}}}{A_{roof}\phi\psi e^{-\zeta v_{ff}} - R_e\left(A_{roof}\phi\psi + \zeta G\right)}\right] \;\; ; \;\; (\%)$$

F.9 Soakaway Pit and Yard Ponding Site Evaluation Form

Adapted from Urbonas and Stahre (1993).

This questionnaire evaluates a site's suitability for installing a yard pond and uses a point system and based on how certain questions are answered. The questionnaire is as follows:

1. What is the ratio of area available for infiltration to the area to be drained?
    - >2 = 20 points; >1.5 = 10 points; >0.5 = 5 points; <0.5 = area too small

2. What is the surface soil type?
    - Coarse with low organic material = 7 points; normal humus soil = 5 points; fine-grained with high organic content = 0 points

3. What is the subsurface soil type?
    - Coarser than surface soil type = same score as surface soil type; Gravel, sand or mix of both = 7 points; Silty-sand or loam = 5 points; fine silt or clay = 0 points

4. What is the slope of the site?
    - relatively flat = 5 points; moderately sloped = 3 points; steep = 0 points

5. What is the vegetation cover?
    - Natural vegetation or natural lawn = 5 points; well established lawn = 3 points; new lawn = 0 points; bare ground = -5 points

6. What is the degree of traffic?
    - Very little foot traffic (ornamental lawn, garden) = 5 points; Average foot traffic (park, moderately used backyard) = 3 points; heavy foot traffic (playing field) = 0 points

Score interpretation:

- >30 points – Excellent suitability
- 20-30 points – OK suitability
- < 20 points – Poor suitability, do not use

For the soakaway pit, a modified questionnaire was used. In the yard pond questionnaire the drainage area is the surface of the lawn available for draining. The drainage area for a soakaway pit is all four sides and the bottom of the pit. Thus the top surface area on its own is not a good indicator for suitability since the infiltration area is actually much greater. Using a pit depth of:

$$d_{min} = \dot{n}T_{drain} = 36cm \text{ (see Section A.F.10 for further details)}$$

a relationship between the area of the top of the soakaway pit and the area available for infiltration can be drawn. However, this criteria is less important for soakaways since the user will quickly find out if they do not have sufficient room on their property for the pit they need.

This change resulted in changing question 1:

1. What is the ratio of the area available for the pit to the area to be drained?
    - >0.15 = 20 points; >0.12 = 10 points; >0.05 = 5 points; < 0.05 = area too small

In a soakaway pit evaluation the surface soil type is irrelevant since the pit sits below the surface soil and the water is delivered directly to the pit. Thus question 2 was eliminated. All other questions remained the same. The score interpretation was changed such that:

- 25 points – Excellent suitability
- 17 – 24 points – OK suitability
- < 16 points – Poor suitability, do not use

F.10 SOAKAWAY PIT SIZING

Adapted from Adams and Papa (2000)

Assumptions:

- pit drain time, T_{drain}, must be less than 24 hours
- the infiltration rate, $\dot{n}$, is at least 15mm/h
- pit is not more than 1m deep

Select reliability of pit, R_p

Determine rain volume to accommodate:

$$v_{rain} = \frac{\ln(1 - R_p)}{-\zeta}\phi \;\; ; \;\; (mm)$$

Determine volume of water to be held in pit:

$$v_{water} = A_{roof} * v_{rain} \;\; ; \;\; (m^3)$$

Determine pit volume with fill media:

$$v_{pit} = \frac{v_{rain}}{p_{fill}} \;\; ; \;\; (m^3)$$

Pit should be long and narrow such that:

$$w_{pit} = \frac{1}{2} l_{pit} \;\; ; \;\; (m)$$

Determine minimum pit depth:

$$d_{min} = \dot{n} T_{drain} = 15\, mm/h * 24h = 36cm$$

Pit volume given by (note the depth can be up to 1m deep):

$$v_{pit} = w_{pit} l_{pit} d_{min} \;\; ; \;\; (m^3)$$

Rearrange to get pit width:

$$w_{pit} = \sqrt{\frac{2 v_{pit}}{d_{pit}}} \;\; ; \;\; (m)$$

F.11 YARD PONDING SIZING

Adapted from Adams and Papa (2000).

Assumptions:

- pond drain time, T_{drain}, must be less than 24 hours
- the infiltration rate, $\dot{n}$, is at least 15mm/h
- pond may be no more than 100mm deep

Select reliability of pond, R_o

Determine rain volume (mm) to accommodate:

$$v_{rain} = \frac{\ln(1 - R_o)}{-\zeta} \phi \;\; ; \;\; (mm)$$

Determine volume of water to be held in pond and hence pond volume:

$$v_{water} = A_{roof} * v_{rain} \;\; ; \;\; (m^3)$$

Pond volume given by (note the depth is user chosen at under 100mm):

$$v_{pond} = v_{water} = w_{pond} l_{pond} d_{pond} \;\; ; \;\; (m^3)$$

The length and width are then selected to meet the volume requirement. As a starting point a square pond would have sides:

$$w_{pond} = l_{pond} = \sqrt{\frac{v_{pond}}{d_{pond}}} \;\; ; \;\; (m^3)$$

F.12 TREES SELECTION TOOL FOR SHADING

Tree Selection Tool

This tree guide can be used to select trees for shading in the summer, allowing light through in the winter, or both. Note that this is not an all-inclusive list of trees that can be used for these purposes but it does list a number of common trees. Do not let this list limit you in your selection of trees, shrubs, or even vines.

To use the tool, look through the chart to determine which trees may be suitable for your needs and list them. Then, from this list, try to select trees that are native to your area.

Heading Explanations

Botanical Name - the scientific name of the tree
Common Name - the name used in general language for the tree
Transimissivity - The amount of sunlight, in percent, that the tree allows through. Both summer and winter values are given for many trees. Trees that have high transmissivity values allow more light through than those with low transmissivity values.
Foliation - When a tree grows leaves in the spring
Defoliation - When a tree loses leaves in the fall
Expected Max Height - The maximum height the tree is expected to grow

Foliation and Defoliation Key

Foliation -	E, Early, Before April 30	Defoliation -	E, Early, Before November 1
	M, Middle, May 1-15		M, Middle, November 1-30
	L, Late, After May 15		L, Late, After November 30
			P, leaves persist through winter

Note that these dates are averages for the tree in its natural range. These date can differ from north to south or on local climactic conditions within the range or if the tree is planted outside its natural range.

Chart adapted from Brown and DeKay (2001), Brown and Gillespie (1995), and Hightshoe (1988).

Botanical Name	Common Name	Transmissivity Range (%) Summer	Winter	Foliation	Defoliation	Expected Max Height (m)
Acer rubrum	Red Maple	15-14	60-75	M	E	20-35
Acer saccharinum	Silver Maple	8-22	60-87	M	M	20-35
Acer saccharum	Sugar Maple	16-27	60-80	M	E	20-35
Aesculus Hippocastanum	Horse Chestnut	8-27	73	M	L	22-30
Amelanchier canadensis	Service Berry	20-25	57	L	M	10-15
Carya ovata	Shagbark Hickory	15-28	66	M-L	E	24-30
Catalpa speciosa	Western Catalpa	24-30	52-83	L	E	18-30
Fraxinus pennsylvanica	Green Ash	10-29	70-71	M-L	M	18-25
Gleditsia tricanthos inermis	Honey Locust	25-50	50-85	M	E	20-30
Juglans nigra	Black Walnut	9	55-72	L	E-M	23-45
Liriodendron tulipfera	Tulip Tree	10	69-78	M-L	M	27-45
Picea pungens	Colorado Spruce	13-28	13-28	P	P	27-41
Pinus strobus	White Pine	25-30	25-30	P	P	24-45
Plantanus acerifolia	London Plane Tree	11-17	46-64	L	M-L	30-35
Populus deltoides	Cottonwood	10-20	68	E	M	23-30
Populus tremuloides	Trembling/Quaking Aspen	20-33	---	E	M	12-15
Quercus alba	White Oak	13-38	---	M-L	L-P	24-30
Quercus rubra	Red Oak	12-23	70-81	---	M	23-30
Tilia cordata	Littlelead Linden	7-22	46-70	L	E	18-21
Sorbus decora	Showy Mountainash	50-60	---	M-L	E	6-10
Betula papyrifera	Paper Birch	40-80	---	E	E	25-30
Cornus florida	Flowering Dogwood	43	53	E	E	10-15
Celtis occidentalis	Common Hackberry	12	---	E	M	23-30
Crataegus phaenopyrum	Washington Hawthorn	24	---	L	M	8-9
Robinia pseudoacacia	Black Locust	38	40	L	E	15-23
Acer negundo	Manitoba Maple/Boxelder	0.13	---	E	E	12-18
Quercus palustris	Pin Oak	15-30	63-88	M	L-P	15-23
Cercis canadendis	Eastern Redbud	62	74	M-L	E	6-10
Platanus racemosa	California Sycamore	9	45-60	---	---	24-30
Liquidambar styraciflua	Sweetgum	18	65-84	E-M	E	23-30

F.13 OUTDOOR ROOM DESIGN TOOL

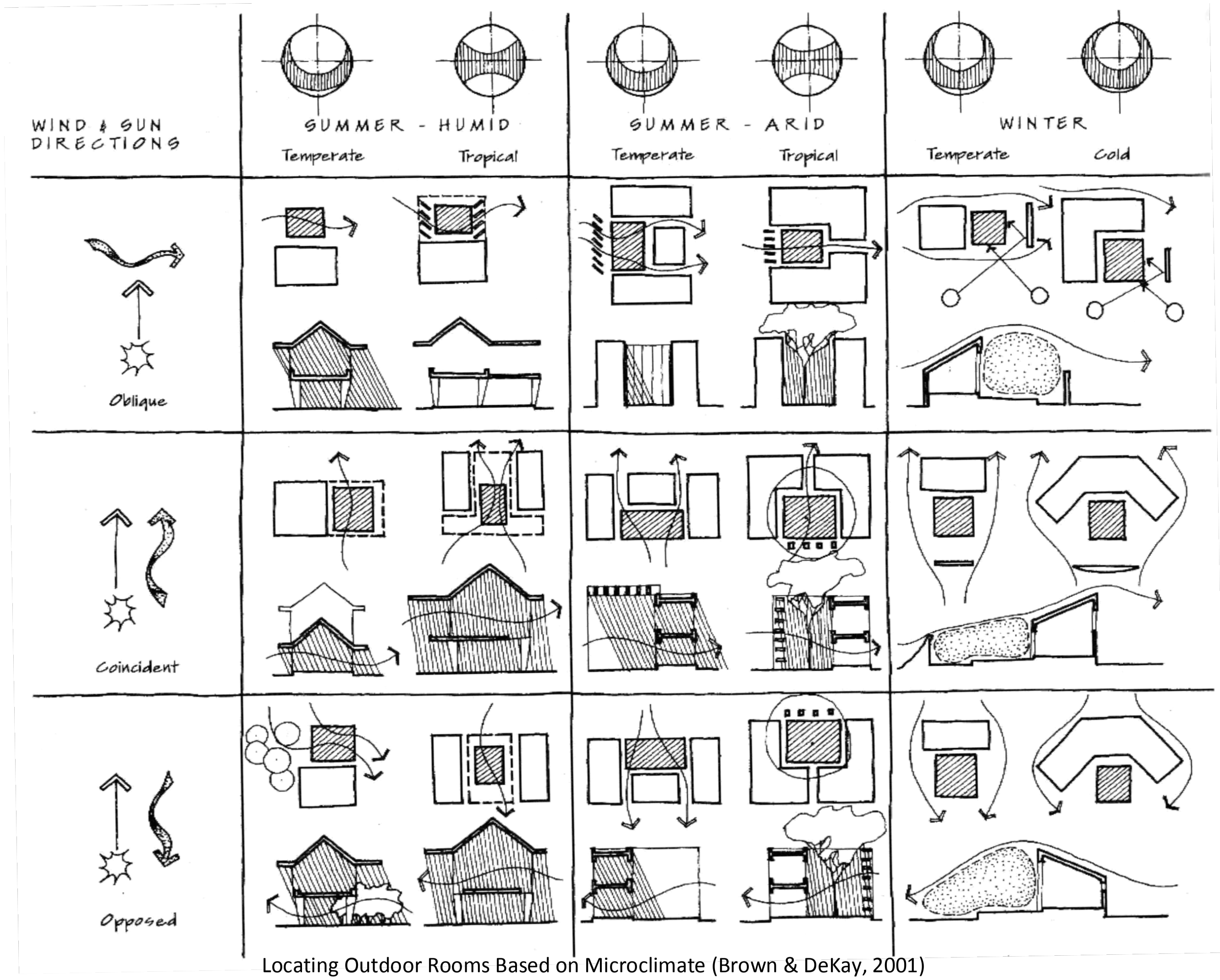
Outdoor Room Design Tool

This tool can help place an outdoor room that can take advantage of wind and sun to make it more comfortable for a longer period of time during the year. Shade and wind can be used to make the outdoor room more comfortable in hot climates or in the heat of the summer. Sun and windbreaks can be used to make them more comfortable during cooler seasons, extending the outdoors room's use into the autumn or even winter months.

Procedure for using the table below:

1. Along the top row find your summer conditions; hot and humid or hot and arid (dry).
2. Along the left-most column find your wind and sun conditions. Does the wind blow in the direction the sun shines most of the time, against the sun, or perpendicular?
3. Find the intersect of your summer conditions and the wind/sun conditions on the chart. This will tell you how to position elements of the outdoor room to maximize comfort. Note that the shaded (hatched) area represents the outdoor room and the white blocks represent the home or other buildings.
4. For use of the room in the cooler months of the year or in generally cooler climates, repeat steps 1-3 but look at the winter conditions column.

Note that buildings can be replaced by other obstructions such as plants, sheds, other homes, or anything lese that will block sun, wind or light as appropriate. Remember that you are limited only by your creativity in the design of the outdoor room.



Locating Outdoor Rooms Based on Microclimate (Brown & DeKay, 2001)