An Introduction to Sustainable Housing Design

By Arran Timms

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Supervising Professor: J.Earnshaw, Trent University

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Statement of Purpose

Rationale for Study

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This is the first in a series of two papers on the topic of sustainable housing written for a third-year Environmental Resource Science reading course. This paper will be an introduction to the topic of sustainable housing in an urban setting. It will include background information and definitions necessary for further examination of the field, set the parameters of study for the course, present a broad socio-economic picture outlining the need for sustainability in our "built environment" and explore basic design alternatives. The second paper will investigate specific building design within the parameters set out by the introductory essay. It will have a more technical and detailed approach to the topic. It will not provide a single house design, but will suggest design guidelines that permit sustainability within the urban context. From these guidelines may arise an image of the ideal sustainable urban house, however it will not be the intention of the second paper to provide such a design. The second essay will also include a certain amount of schematic illustration and/or drawings, as required by its technical nature.

Rationale for Study

I became interested in the idea of the "sustainable house" through the merging of a life-long interest in architecture and my studies in environmental science at Trent. Architects are now beginning to fully realize that the idea of environmental responsibility - or "sustainability" - is integral to our built environment, that is, the physical structures in which our society lives and works. "Architects are beginning to form a consensus on an environmental agenda, this time with an urbanistic bent (*Progressive Architecture* 1993)." Two decades ago, during the 1970's, revolutionary architectural thought evolved that was dominated by a new-found interest in energy efficiency and the exploration of solar power and other alternative energy forms. Today, the emerging consensus on sustainable architecture is more complete, and perhaps more pragmatic and utilitarian, than was earlier thought. This new agenda includes a comprehensive list of design issues, many of which were unconsidered until relatively recently. I intend to investigate these issues with the goal of creating an inclusive and informative research document on the topic of sustainable housing.

Introduction

Sustainable housing is both a very large and a very inter-disciplinary topic. The term "sustainable" is, in itself, quite broad and open to interpretation. The *Concise Oxford* defines the verb *sustain* as to "maintain, or keep going continuously." In essence, a sustainable environment is just that--one that is maintained in a balanced and conservative manner such as to allow for its own continuance. Sustainable housing, then, is built structures that permit the maintenance and continuity of the natural environment by not degrading our finite biosphere. However, the realistic parameters for sustainability in the built environment are not clear. Certain constraints exist to the idea of sustainable housing. Housing consumes energy and resources by necessity. Obviously, we need to minimize the environmental stress caused by the housing needs of our society. This is the fundamental goal of sustainable housing. Sustainable housing design should attempt to protect, not exploit, the world in which we live.

Part I of this paper will examine the need for sustainable housing in a historical context. The goals of sustainable housing will be explained in *Part II*. *Part II* will also briefly explore the concept of self-sufficiency. *Part III* will outline the parameters for sustainable housing design that will be addressed more thoroughly in the second paper.

I. The Need for Sustainability in the Built Environment

> The overwhelming lesson of the last decade is the recognition that the world's resources are finite and that man has to use them rationally in order to continue to survive on a crowded planet. It is characteristic of the years since Rachel Carlson, Barbara Ward, Rene Dubos and others focused our attention on these facts that we have recognized that the world's finite resources are in collision with man's infinite needs and desires (Ortega 1981).

Society has lived far beyond its means. It is now evident that unprecedented environmental degradation and resource depletion has resulted from the consumer lifestyle characteristic of post-war Western society. Housing, a principal part of this lifestyle, is no exception to the pattern of environmental destruction. About half of all global-warming-contributing greenhouse gases produced each year by industrialized countries are related to the built environment, through the use of energy (Mackenzie 1991). Chlorofluorocarbons, that cause severe stratospheric ozone damage and consequent environmental problems, have been, and in some cases still are employed in buildings in rigid polyurethane and polystyrene foams (as insulative materials), as refrigerants in air-conditioning systems and in fire protection equipment. Forest destruction results, on a very large scale, as a result of the housing construction industry, where as much as 10 per cent of the lumber purchased for construction can end up as waste (CHMC 1993). Almost 15 per cent of landfill waste comes from the residential and commercial construction industries at a time of waste-disposal crisis. Twenty per cent of Canada's total energy consumption is used to heat, cool and operate our homes (CHMC 1993). The combustion of fossil fuels, in particular natural gas and oil, for space and water heating purposes, contributes, in addition to global warming, to acid rain and air pollution. Electricity used for lighting and appliances and, in some instances, also used for space and water heating, is certainly not without its environmental concerns either. The environmental impacts of utility-generated electricity, from coal-thermal, nuclear-thermal or hydroelectric power plants include soil, water and air pollution, respiratory illness, acid deposition, hazardous waste disposal, natural habitat destruction and the release of ionizing radiation.

It is obvious that the need for sustainable housing is real. While it may seem an encyclopaedic list, the environmental consequences of consumptive housing patterns enumerated above are not totally inclusive. Sustainable housing design must consider even more interests than those listed, such as the environmental impacts of water use, land use and human environmental health concerns. However, the list is conclusive enough to illustrate a point. The role of the professional architect in design that addresses these critical environmental issues is very important.

> In this age of mass production when everything must be planned and designed, design has become the most powerful tool with which man shapes his...environment (and by extension, society and himself). This demands high social and moral responsibility from the designer (qtd. in Mackenzie 1991).

Hence, it seems that the onus is on the architect to create a housing environment that is sustainable. It is true that "the designer, as the principal determinant or creator of the product itself (Mackenzie 1991)", has a direct influence on the amount of environmental damage which will occur as a result of that product, however, the demand for the product must also be examined. This demand is exemplified by the consumer lifestyle prevalent in contemporary society. The problem with a consumer lifestyle is that it places unreasonable demands (in an ecological sense) on the biosphere. Before true sustainability can be achieved, radical change to the consumer lifestyle must be effected. Only fundamental transformation of conventional thought processes (*ie*. conservation *vs*. consumption and "waste" as resource) will permit the success of sustainability in our built environment. Thus the role of the designer in leading this change is essential, but the role of the consumer is paramount.

The History of Sustainable Housing

The precedent for *un*sustainable housing was set during the late 1940's in Levittown, New York. Named after the man who pioneered this type of housing, it was the first post-war suburb in America. Levittown was a massive development, literally unequalled anywhere in magnitude, that exploited a profitable ideal--The American Dream. Its design emphasized the housing concerns of the times. Consumers desired private, self-contained housing units, with an emphasis on homeownership and upward mobility, albeit at the sacrifice of public space, public transportation and social services, and with no concern for energy or resource conservation. Don Mills, Ontario, a Canadian parallel of the Levittown model, was based on the same principle tenets of post-war suburbia. It was land-consumptive, use-segregated, low-density housing.

The Suburban Dream House stressed the consumer ideals of post-war America with complete disregard for the natural environment. Inherent in housing design of Levittown's type were the following: neglect for regional climate due to standardized plans and materials that helped create patterns of unseasonable heat gain and heat loss which were compensated for by year-round air conditioning or intensive heating; disregard for siting and landscaping as the same house was built facing north, south, east and west and vegetation, including shade trees, was bulldozed in the name of progress; the use of water as a waste transport medium; the use of energy intensive heating and lighting systems and appliances; dependence on municipal utility infrastructures; low density development; and dependence on the automobile, as Levittown's suburban setting necessitated automobile access via a highway system.

Unfortunately, the suburban model has been the dominant housing choice since it was introduced to North America. Almost three-quarters of the current housing stock in the United States has been built since the 1940's. "Americans chose the Levittown model for housing in the late 1940's; we have mass-produced the home as haven and transformed our cities to fit this model and its particular social, economic and environmental shortcomings (Hayden 1984)." It was a poor choice. "American dream houses and their dispersed settlement pattern used more non-renewable resources than any society had ever used before, because builders had assumed that energy would always be cheaper than materials and labour (Hayden 1984)." As was learned definitively three decades later during the 1970's, this was an unsound assumption.

The unsustainable housing trend continued until this decade, when energy and resource shortages, particularly petroleum reserves, were predicted. At the same time, society was being made more aware of the environmental consequences of the post-war consumer economy. Hence a new-found eco-consciousness. Alternative energy systems and energy conservation practices for housing were developed in this climate of increased environmental awareness and concern over a rapidly decreasing natural resource supply. However, in most cases, the approach to sustainability was not complete. For example, the R-2000 housing program, a Canadian housing energy conservation program, developed during the 1980's, did not truly challenge the consumer lifestyle. It employed many of the tenets of this period of greater energy efficiency, but continued to promote affluent, two-car, suburban living. This period lacked sufficient methodical change necessary for true sustainability.

Today, through the prolonged economic stress of recent years (and perhaps due to increased education), a new economic picture is developing that is causing renewed interest in lifestyle change. A fundamental principle that has always been ignored has now been realized--that the economy and the environment are integrally connected. It is now recognized that sustainability, in housing or any other sector, is economically efficient because it is resource efficient. To what extent this shift in thinking will occur is not yet apparent. Clearly, there will have to be a balance maintained between idealism and realism.

II. The Goals of Sustainable Housing

Realistic goals of sustainable housing design are four-fold: to eliminate the current dependency on non-renewable fuels for energy needs by the use of alternatives, to maximize resource efficiency, to protect environmentally significant areas and to reduce or eliminate pollution-generating activities associated with all aspects of conventional housing.

To Eliminate the Current Dependency on Non-renewable Fuels for Energy Needs

The environmental impacts associated with energy use are many. Significant environmental degradation is known to result, in particular, from the combustion of fossil fuels, whether by the end-user (a household) or an electrical generating utility (that supplies electricity to the household). The over-consumption of Western society of this type of energy is aptly described in the following quote, which explains the context of our extraordinary reliance on fossil fuels:

> Each of us should be aware that the era in which we live is extraordinarily specialized and set off from all human history and future on this planet by our use of fossil fuels. These energy resources were laid down over hundreds of millions of years during the earth's evolution and they are now being consumed in what is essentially an instant occupation of our planet (Kraushaar 1988).

Not only has the consumption of this non-renewable resource been seemingly instantaneous, it has had severe impact on the biosphere and will continue to adversely affect the natural environment for as long as we depend on it for the majority of our energy needs.

To Maximize Resource Efficiency

It is recognized that natural resources must be consumed to fulfil society's housing requirements. However, this consumption of valuable, non-renewable resources can be minimized. Applying the 3R hierarchy (reduce, reuse and recycle) to conventional housing systems will help yield resource efficiency. Sustainability typically exercises reduction through resource conservation and resource reuse from the secondary use of materials. It is important to note that recycling is at the bottom of the hierarchy. Most building products exhibit what is known as cascading recyclability. Cascading recyclability is the processing of used materials to create a single secondary product, that, when it reaches the end of its lifespan, cannot be reprocessed further. It is not a closed-loop system. True recyclability occurs when a material can be recycled over and over again.

It is essential to assume a life-cycle approach when assessing the environmental impact of resource consumption. A product itself consumes materials, but supplementary resource consumption and energy use occur at many levels. A full life-cycle assessment must begin with the extraction of the raw material from the resource base and include evaluation of the transportation of the resource to factories, the processing and manufacturing of the product, the dissemination of product information, the transportation of products to construction sites, the construction process, the habitation, operation and maintenance of the completed building and finally the disposal or reuse of the material. The architect, then, must consider all levels of the life-cycle strategy and the embodied energy inherent within each level when considering a potential building product. There exists substantial opportunity for materials specification that will minimize resource consumption.

To Protect Environmentally Significant Areas

Prime agricultural lands, wildlife habitat and wetlands are being replaced by the rapidly expanding metropolis. These environmentally significant areas must be protected by the encouragement of **a) urban intensification** rather that low-density suburban sprawl and **b) sustainable community planning**.

To Reduce or Eliminate Pollution-Generating Activities Associated With Housing

The last and perhaps most important goal of sustainable housing is to reduce, and where possible, eliminate air, soil and water pollution associated with all aspects of conventional housing, from the construction process to occupancy. Again, the importance of the life-cycle approach should be stressed. Only in this way can we ensure the conservation of the natural environment for the benefit of present and future generations, for "Of what use is an environmentally sensitive home if we do not have a planet to put it on (qtd. in CHMC 1993)"

Self-sufficiency

Self-sufficient housing will be considered a sustainable alternative to conventional housing systems. The dictionary defines *self-sufficient* as "needing nothing; independent; able to supply one's needs for a commodity from one's own resources." Pursuant to the concept of the self-sufficient house, "One's own resources" would refer to the following: **a) sustainable renewable resources**, *e.g.* solar energy and the hydrological cycle, **b) recycled resources**, *e.g.* recycled building materials, grey-water reuse and waste heat energy use and **c) natural**

biological processes *e.g.* agriculture and decomposition. Self-sufficiency in the urban environment assumes independence of municipal utility supply infrastructures, such as the energy grid. The extent to which self-sufficiency can realistically occur has yet to be determined, however, current technology does exist that would permit the construction of a "self-sufficient" house.

III. Parameters of Study - Sustainable Housing Design in an Urban Setting

The model of sustainability that follows will include the following design concerns: energy, waste management, landscaping and land use, water, environmental health, construction and affordability. Each issue is critical to a comprehensive and inter-disciplinary approach to sustainable housing design in an urban setting.

Energy

Energy use in housing is composed of space heating and cooling (67%), lighting and appliances (18%) and water heating (15%) (CHMC 1993). Clearly, the largest opportunity for energy conservation is available in the first energy use category. To realize our first goal of sustainability, to eliminate society's extraordinary dependency on non-renewable energy, sustainable housing should employ the following in its design **a) self-sufficiency** of the electrical grid, **b) sustainable alternative energy systems**, that include, for example, passive and active solar gain, photovoltaics, biomass energy and wind energy (although the latter is not very practical for the typical urban setting), **c) energy conservation**, through minimal envelope heat loss in the winter and heat gain in the summer by super-insulation of all heat loss areas and the use of low-emissivity triple-glazed inert gas-filled windows, insulative building materials, skylights, temperature buffer zones and proper orientation and landscaping, **d) energy efficiency**, where energy efficient heating and ventilation systems, entrances, appliances and lighting systems *(e.g.* fluorescent and halogen) are standard. It should be emphasized that all the above conditions must be applied together for successful sustainable design--a single alternative energy system, for instance photovoltaics, will not suffice in the absence of energy conservation and efficiency. In fact, photovoltaics cannot realistically operate as a standalone system. During the night-time or on overcast days, when electricity is still required within the household, additional alternative energy systems must be employed. The thermopile, an electricity-generating biomass heat engine, is one example of such a supplementary system.

Waste Management

Sustainable housing should also attempt to be self-sufficient of the municipal sewage and solid waste disposal infrastructure. In particular, the cost of a water-borne sewage system is significant and unnecessary. The cost of purifying waste water (sewage is 99% water) is the cost of purifying the transporting medium, rather than the waste, and thus represents a misuse of energy and resources (Rybczynski 1976). Municipal sewage treatment facilities are not only unnecessary, but in many metropolitan areas are overburdened and can contribute to local environmental health problems. For instance, NDMA (N-Nitrosodimethylamine), a carcinogenic compound, is the inadvertent by-product of chemical processes used in some sewage treatment plants (Ontario Ministry of the Environment 1990).

It is clear that non-chemical, *in situ* sewage treatment would provide a far more sustainable alternative. Biological sewage waste management within the sustainable house can take a few forms, including **a) solar aquatics**, an "eco-engineering" process, whereby aquatic plant and animal organisms process all waste water producing a potable end-product, and **b) the composting toilet**, for example, the Clivus Multrum or other double vault composting toilet systems, or a combination of these two alternatives.

Solid waste management must follow the 3R hierarchy. To this end, household hazardous waste must be eliminated, and vermicomposting (composting by worms), or community-based composting in population-dense urban areas should be promoted. Compost production, for use as fertilizer in the garden, is integral to the idea of the self-sufficient house.

Landscaping and Land Use

Siting of the sustainable house should be typified by efficient site planning that considers bioregionalism (local climate, *etc.*), natural landscape, microclimates and physical constraints of site. The third goal of sustainable housing - to preserve environmentally significant lands - will be achieved expressly through urban intensification. Another important land use concern is integration with sustainable community practices, that is, integration with diverse-economy, pedestrian communities.

Sustainable housing should be landscaped to support food production, natural, organic gardening, and site shading--deciduous trees provide shade in summer and allow sunlight in winter. Water-efficient ornamental or decorative gardens, characterized by drought resistant varieties, should be planted. Natural wind breaks should be employed to reduce heat loss. Finally, indoor greenhouse gardens should be incorporated into the design for winter food production.

Water

Conventional water usage in the home is composed of toilet flushing (45%), showers and baths (28%), laundry and dishes (23%) and other kitchen use (3%) (CHMC 1993). The sustainable house should be self-sufficient of the municipal water supply. Consequently, it requires a rainwater recovery system and related purification and storage systems. The volume of rainwater recovered from the rooftop system is directly proportional to the catchment area (roof size), but should be sufficient for all household uses if water conservation and water recycling are also practiced. Water conservation includes the use of flow restrictors, metering faucets, water-saving showerheads, low flush toilets (if non-composting) and can reduce household water consumption by up to 30%. Reuse of grey-water (waste water from non-toilet plumbing fixtures and appliances) in garden irrigation systems will also reduce overall water demand.

Environmental Health

Indoor air pollution can be three to four times greater than outdoor air pollution. The sustainable house avoids this problem by preventing the outgassing of toxic vapours from synthetic or chemically treated building materials, carpeting, cleaning substances and furniture through careful materials selection. Biological irritants such as mould, pollen and bacteria can also be eliminated by proper ventilation. Water quality should be assured by the rainwater treatment system. Other human health concerns, including radioactive soil gases, light, noise, and electromagnetic radiation should be addressed by the siting and design process.

Construction

Construction of the sustainable house necessitates the use of "green" building materials, of which there are multitude available. Typical products are those with **a) recycled content**, **b) durable and long-lived building components**, **c) non-toxic, non-outgassing products** (inert materials that contain metal, glass or concrete that are also easily recycled), **d) recyclable materials**, and **e) building products with low embodied energy** as determined by life cycle assessment. Sustainable construction processes include **a) proper management of construction waste**, for example, masonry, wood, corrugated cardboard, metal and drywall recycling, **b) efficient use of building materials**, for instance, the use of leftover framing wood in non-structural applications and the proper handling and storage of materials to avoid damage and **c) materials salvage and reuse**.

Affordability

For sustainable housing to be a practical, economically viable alternative to conventional housing, it must be affordable. In fact, it should be cheaper. Sustainability will save the homeowner money for a number of reasons. First, the self-sufficient house is smaller, by necessity, than its typical suburban counterpart. Instead of wasting space and resources, it exploits this opportunity for conservation. Also, less costly construction, the use of recycled resources as opposed to virgin resources and the virtual elimination of utility bills will all contribute to the affordable sustainable house.

Conclusion

As Dr. Schumacher, another well-known scholar and author associated with the early environmental movement, noted over a decade ago, small is beautiful. A re-evaluation of society's ideals along these lines would recognize that small is also cheap. By practicing conservation, not only does the architect and homeowner reduce the economic cost of building and operating the home, they vastly reduce housing's true cost--the economic *and* environmental expense associated with conventional housing.

References[†]

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Ortega, Alvaro. 1981. Building ecologically: a seminar with Alvaro Ortega: proceedings. Centre for Human Settlements, University of British Columbia, Vancouver.

Rybczynski, Witold, *et al*. 1976. Stop the five gallon flush!: a survey of alternative waste disposal systems. Minimum Cost Housing Group, School of Architecture, McGill University, Montreal.

[†] This list of references ascribes only those materials referenced directly in this paper. Many other resources were referred to in the researching of this topic. A complete list will be given at the end of the second paper in the form of a bibliography.

Other Finalists

Suburban Detached

Maniwaki Centre Adult Education Services
Team: Bruno Billard, Roland Léveillé, Charles Lemay, Al Townsend and Ray Thomas
Design: A small pre-fabricated bungalow suitable for northern and remote sites.
Features: Energy efficiency and independent power supply through high efficiency wood heat, PV and solar DHW.
Contact: Bruno Billard,
Western Québec Regional School Boards,
19, rue Principale nord,
Maniwaki (Québec), J9E 2B1.
Telephone: (819) 449-1731

Retrofit

Mireille Jean Architecte
Team: Mireille Jean and Dr. Daniel Bindley
Design: This project addresses the retrofit of a 3 bedroom bungalow and is applicable to a large number of houses across Canada.
Features: Updated floor plan and high levels of energy efficiency through exterior retrofit of thermal envelope.
Contact: Mireille Jean,
Mireille Jean Architecte,
1515, rue des Cédres,
Chicoutimi (Québec), G7H 1C2.
Telephone: (418) 693-8466

Urban Infill

BLP/ Philip Sharp Architect/Drerup Armstrong Ltd.
Team: Don Buchan, Philip Sharp, Oliver Drerup and Jeff Armstrong
Design: A block of seven non-profit housing units designed for the environmentally hypersensitive.
Features: An example of 'clean-air housing' and high levels of energy efficiency.
Contact: Don Buchan,
BLP Ltd.,
5370 Canotek Road,
Ottawa, Ontario K1J 9E6.
Telephone: (613) 748-3762

Robert Parker Associates Ltd., Architects and Planners
Team: Robert Parker, Jennifer Corson, Greg Ewert, John Woods and Gordon Radcliffe
Design: A two-storey frame dwelling with one, two and three bedroom units designed for "cluster" development on an urban site.
Features: Eighty per cent reduction in construction waste, high levels of energy efficiency and extensive water conservation features.
Contact: Robert Parker,
Robert Parker Associates Ltd.,
1331 Brenton Street,
Halifax, Nova Scotia, B3J 2K5.
Telephone: (902) 420-1277

The Jury

Dr. Stephen Barron: Family Physician, Vancouver.

Professor Robert Besant: Head of Mechanical Engineering at the University of Saskatchewan.

Dr. Avi Friedman: (Jury Chairman): Professor of Architecture and Director of the Affordable Homes Program at McGill University, Montreal.

Richard Kadulski: Architect and publisher of Solplan, a newsletter on low energy building and building science, Vancouver.

Kathleen Kurtin: Architect specializing in renovations and conversions, Toronto.

Richard Lind: Builder/renovator, Vice-Chairman, Technical Research Committee of Canadian Home Builders Association, Bridgewater, Nova Scotia.

Christian Ouellet: Architect, President of Solar Energy Society of Canada, Lac Brome, Québec.

Rick Quirouette: B. Arch., Building Envelope Consultant with Morrison-Hershfield, Ottawa.

Dr. Virginia Salares: Chemist, specialist in housing for the environmentally hypersensitive, contract staff with Research Division, CMHC, Ottawa.

For more information on the House Designs of the Winners, Honourable Mentions and Finalists, contact them directly at the address above or contact:
The Canadian Housing Information Centre (CHIC)
700 Montreal Road,
Ottawa, Ontario K1A 0P7
Tel: (613) 748-2367
Fax: (613) 748-4069

Canada Mortgage and Housing Corporation (CMHC) offers a wide range of housing-related information. For details, contact your local CMHC office.

Cette publication est aussi disponible en français.

March, 1992.

CMHC subscribes to the sustainable development theme of the federal government. Quantities of our publications are limited to market demand; updates are produced only when required; and recycled or environmentally friendly stock and environmentally safe inks are used wherever possible.

CMHC SCHL
Helping to house Canadians

CMHC'S
HEALTHY
HOUSING
DESIGN
COMPETITION

HEALTHY FOR PEOPLE – HEALTHY FOR THE ENVIRONMENT

WINNERS AND HONOURABLE MENTIONS

Canada

THE COMPETITION

Canada Mortgage and Housing Corporation is pleased to announce the results of the Healthy Housing Design Competition. The winning entries and finalists demonstrate that it is possible to design houses for the Canadian climate which are in keeping with the principles of sustainable development — houses which offer healthy indoor environments, conserve resources, are environmentally responsible and which remain affordable.

Entrants were invited to develop residential designs in one of three categories: Suburban Detached, Urban Infill and Retrofit. Designs were to be generic rather than site specific, with elements capable of being widely adopted for a variety of houses, sites and regions in Canada.

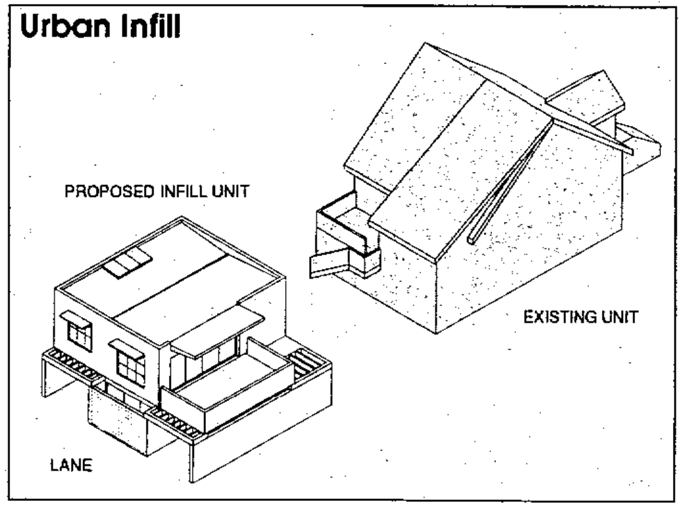
Ten Finalists were chosen from over seventy submissions received in Phase I of the Competition. Submissions from the Finalists were evaluated, in February 1992, by a Jury on the basis of the Technical Requirements which included occupant health, energy efficiency, water consumption, waste reduction and construction and operating costs. Entries were also evaluated on the extent to which they were able to synthesize the technical issues with issues of design, form, and function.

Two winners were awarded — both in the Urban Infill category. Four Honourable Mentions were awarded — two in the Suburban Detached category and two in the Retrofit category.

CMHC is planning a demonstration and monitoring phase for the Healthy Housing Design Competition, with site locations and other details to be announced later in 1992.

THE WINNERS

Urban Infill



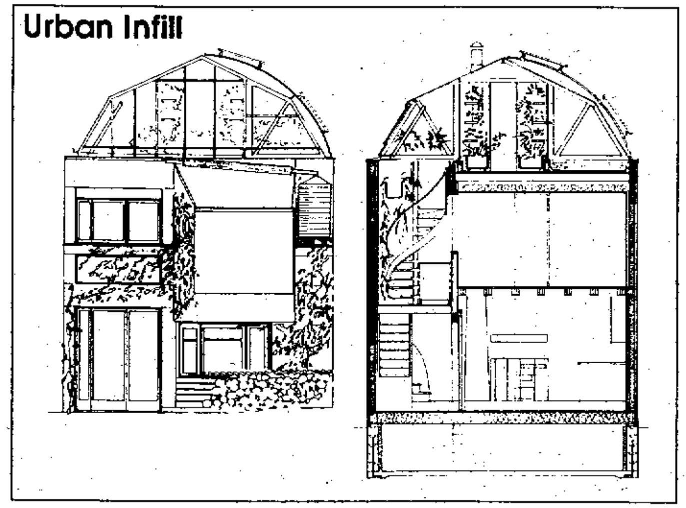
Habitat Design + Consulting and Greg Johnson Architecture/Engineering
Team: Chris Mattock, Greg Johnson, David Rousseau, Pietro Widner and Kay Ferguson
Design: A two-storey, one bedroom, frame dwelling suitable as a granny or rental unit on an urban lot with an existing house.
Features: High levels of energy efficiency and indoor air quality.
Contact: Chris Mattock, Habitat Design + Consulting,
3683 West 4th Avenue, Vancouver, B.C., V6R 1P2.
Telephone: (604) 733-5631
Facsimile: (604) 733-5031

"Attractive without detracting from principle residence — solves problems nicely."

"Is very technically competent and very workable and uses available technology. The real innovation is in the housing design.".

— *selected juror comments*

Urban Infill



Martin Liefhebber Architect Inc.
Team: Martin Liefhebber; Mario Ortuzar, Allen Associates; Lighting Perceptions Inc.; Reid, Jones, Christofferson; Horticultural Management; and Tales of the Earth.
Design: A two-storey, 2 bedroom frame dwelling with a roof-top greenhouse, designed for the rear portion of an urban lot.
Features: A completely autonomous house with independent energy and water supply and sewage disposal systems.
Contact: Martin Liefhebber,
177 First Avenue, Toronto, Ontario, M4M 1X3.
Telephone: (416) 469-0018
Facsimile: (416) 469-0987

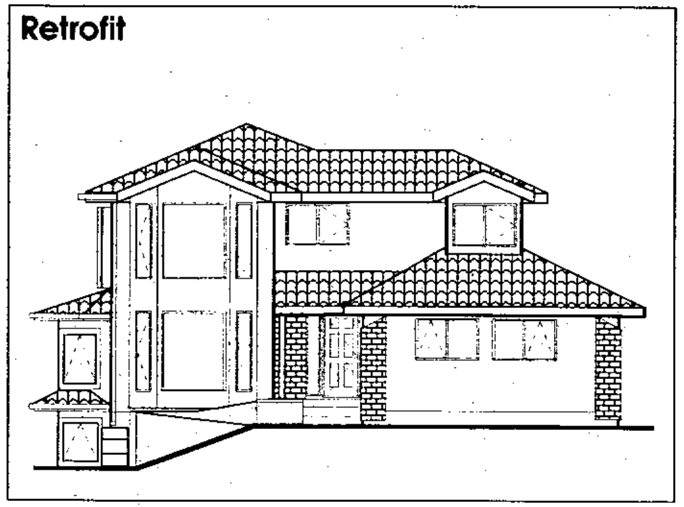
"Revolutionary in getting off grids — gas, electricity and water — yet coming in at a very reasonable cost."

"To build this entry would be to push the development of housing design and technology."

— *selected juror comments*

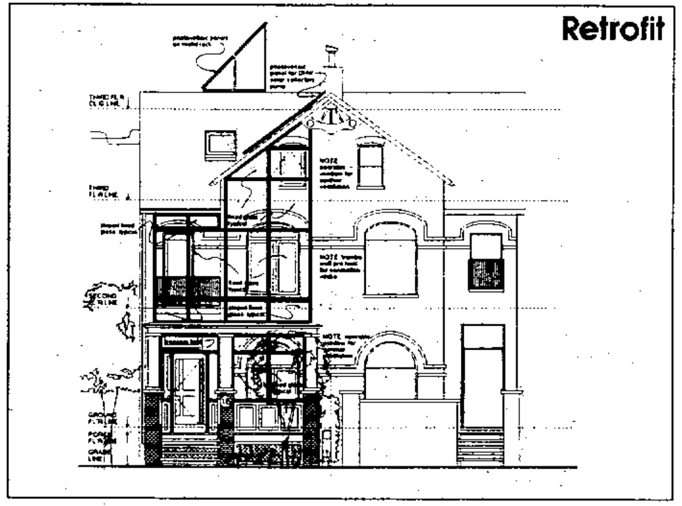
HONOURABLE MENTIONS

Retrofit



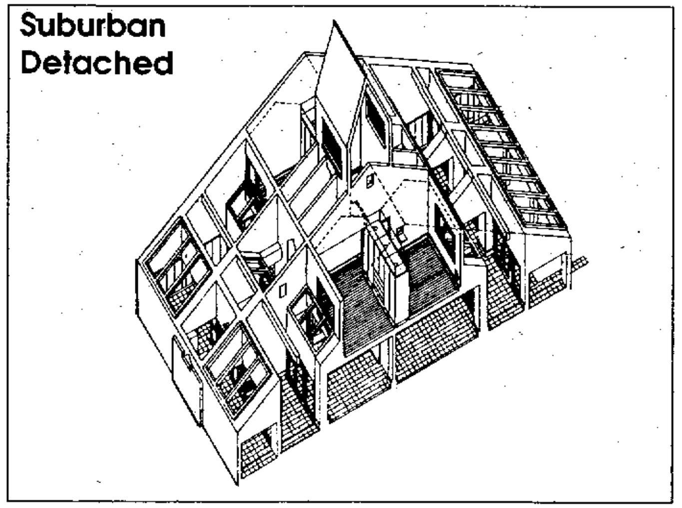
A.R.E. Alternative and Retrofit Energies Inc.
Team: Jorg Ostrowski, Helen Ostrowski, Orion Low and Tony Argento
Design: The retrofit of a large two-storey suburban home to provide 3 units, one for persons with disabilities.
Features: Extensive use of solar energy and 67% reduction in water use.
Contact: Jorg Ostrowski, Alternative & Retrofit Energies Inc.,
1700 Varsity Estates Drive N.W., Calgary, Alberta, T3B 2W9.
Telephone: (403) 239-1900

Retrofit



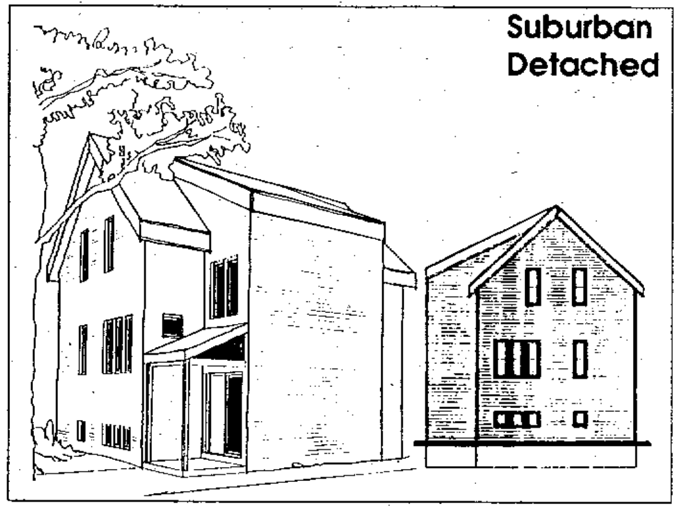
Urban Environment Centre
Team: Robert Tmej, Greg Allen, Roger Algie, Ed Lowans, Henny Markus, Michael Holm, and Rob McMonagle
Design: Retrofit of a large, semi-detached century home to include a suite for a hypersensitive individual.
Features: Emphasis on indoor air quality and solar contribution.
Contact: Robert Tmej, Urban Environment Centre,
16 Howland Rd, Toronto, Ontario, M4K 2Z6.
Telephone: (416) 327-1489

Suburban Detached



Studio 125 Inc. Architect
Team: Blake Millar, Jiri Skopek, Goodfellow Consultants, Charles Pilger, Roger Todhunter, George Banz, John Doggart, Michael Ankenmann, Dr. Joseph Krop and Richard Tamkin
Design: A 4 bedroom, centre hall plan, single family home, also suitable for row housing.
Features: indoor air quality and efficiency in energy and water use.
Contact: Blake Millar, Studio 125 Inc. Architect,
125 Kingsway Crescent, Etobicoke, Ontario M8X 2S3.
Telephone: (416) 233-5785

Suburban Detached



Healthy Homes Consulting
Team: Robin Barrett, Tom Livingston, Tom Emodi and Peter Meridew
Design: A two storey, 3 bedroom frame home, designed for a "cluster" development.
Features: High levels of energy efficiency; staged construction provides affordability.
Contact: Robin Barrett, Healthy Homes Consulting,
20 Maplewood Court, Lower Sackville, Nova Scotia, B4G 1B6.
Telephone: (902) 864-1955

Sustainable Housing Design In An Urban Setting

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Introduction

This is the second paper in a two-part study of the topic of sustainable housing. It is the culmination of a year's research, undertaken for a third-year Environmental Resource Science reading course at Trent University. Whereas the first paper presented a broad ecological and socio-economic picture outlining the need for sustainability in our "built environment" and introduced the topic of sustainable housing in an urban setting, the following text will investigate specific building design within the parameters set out by the introductory essay. It will have a more technical and detailed approach to the topic. It will not provide a single house design, but will suggest design guidelines that permit sustainability within the urban context. From these guidelines may arise an image of the ideal sustainable urban house, however it will not be the intention of this paper to provide such a design, but rather to offer various alternatives to conventional housing systems.

The paper is divided into seven separate sections, each of which represents a design parameter. *Section I* examines landscaping and land use issues. *Section II* discusses indoor environmental health concerns. *Section III* addresses the problem of waste management. *Section IV* examines water supply and water use within the sustainable house. *Section V* discusses sustainable construction processes and environmentally "conscious" building materials. *Section VI* examines energy as it relates to sustainable housing. Finally, *Section VII* examines the issue of economic viability of sustainable housing.

I. Landscaping & Land Use

> Over 60 percent of Canada's housing stock is made up of single-family, detached dwelling units. These units are the least dense of housing options and the most consumptive in terms of land, energy and water. Sprawling development patterns require large tracts of land for housing and for the roads that this auto-oriented form of

> development entails...[this] development pattern is also more energy intensive in both construction and operation (Canada Mortgage and Housing Corporation 1993).

Sustainable housing will mitigate the environmental impacts associated with the conventional housing patterns described above, on two levels. First, on the community planning level, by practicing urban intensification and other sustainable community activities, for example, integration with diverse-economy, pedestrian neighbourhoods, and secondly, on the site planning level, with its emphasis on specific energy, land and water-efficiency issues.

Sustainable housing should practice a) sustainable community planning, and b) site planning that protects environmentally significant land areas and maximizes resource efficiency.

Siting

Siting of the sustainable house should be characterized by efficient site planning that considers bioregionalism, natural landscape, microclimates and physical constraints inherent in the site. The site on which a house is located commits the structure and its occupants to specific environmental conditions. These natural environmental conditions, or site determinants, can be physical or climatic.

Physical site determinants can include subsurface characteristics, topography, vegetation and the presence of surface water. Subsurface characteristics, such as soil composition, water table depth, subsurface rock formation and others, may effect the location of the house on a site. Natural landforms determine local run-off patterns (drainage) and slope. A site with a 2-4% grade with southern orientation is ideal, because in the northern hemisphere, during winter, southern slopes receive greater solar exposure (hence, greater solar gain) due to the low angle of the sun in the sky. Topography is also an important determinant in wind velocity and local wind patterns.

Vegetation has a large effect on the microclimate surrounding a house. Trees and shrubs on the site can act as windbreaks, have a cooling effect in the summer, and filter the surrounding air of pollutants. Dense growth on the site can provide a sound barrier for the occupants of the house. Surface water can moderate air temperatures and reflect sunlight for solar heat gain.

Climatic site determinants include temperature, humidity, precipitation and wind. An evaluation of temperature must consider both temperature extremes and averages of daily and seasonal cycles. Temperature patterns must be equated with heating requirements. Precipitation totals and averages should be studied in their relation to structural capacities of the house and rainwater recovery systems. Wind is a very important site determinant as winter wind greatly increases convective heat loss from the thermal envelope.

The ideal site for the sustainable house (in the northern hemisphere) maximizes passive solar heat gain through unimpeded access to solar radiation during the winter months, is located on a gradual, southern slope, and is sheltered from convective heat loss (particularly maximizing winter wind buffering) by topography and natural vegetation.

Although it is not always possible to select ideal sites (especially in urban areas), siting of the sustainable house should, wherever possible, make efficient use of land while creating desirable microclimates and addressing the physical and climatic conditions inherent in the site.

Orientation

The sustainable house should maximize solar exposure to optimize solar gain and allow the use of solar energy technologies.

Principles of heat transfer that affect orientation include net energy gains that occur through south-facing windows (if properly insulated) during daylight hours, and net heat energy

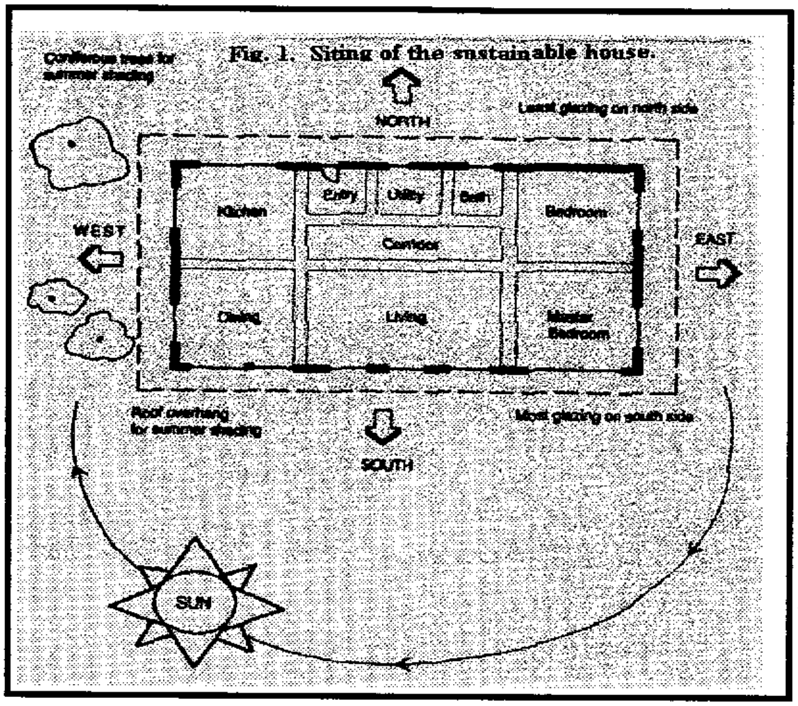


Fig. 1. Siting of the sustainable house.

losses that occur from windows facing any other direction (particularly north). Thus, the sustainable house should be oriented to maximize the opportunity for south-facing glazing. Unheated and occasionally heated rooms should be located on the north side of the house. Frequently used living areas should be located on the southern elevation. Accordingly, northern-most spaces should act as buffer zones of temperature difference between the warmer, more southern living spaces. East, west and particularly north exposures should be maintained at a minimum. The majority of the roof area should be oriented and sloped towards the south to maximize solar exposure for active solar heating and photovoltaic systems.

Landscaping

> The sustainable house should be landscaped to support food production, natural, organic and water-efficient gardening, winter wind buffering and summer site shading.

Deciduous shade trees that are planted on the southern and eastern elevations provide summer cooling while allowing passive solar heat gain during the winter. However, species should be carefully selected and located to ensure that tree branches do not block winter solar radiation. Coniferous species should be planted on the western and northern elevations to provide windbreaks. Heat-reflective landscaping should be also utilized on the southern elevation to increase solar gain.

Sustainable housing should employ groundcovers and ornamental and decorative gardens that are characterized by water-efficient, drought resistant plant varieties to minimize water use. The xeroscape garden program, originating from the American Southwest, is one example. These gardens do not require fertilization, watering or nutrient-rich soils to flourish. Buffalo grass, a native species (unlike the grasses that cover most Canadian lawns) that is extremely drought resistant, is not only water-efficient, but maintenance free as well because it grows to a maximum of 3 inches.

Permaculture is a diverse backyard food production system characterized by perennial food-producing plants, fruit trees and vegetable gardens. Species planted on the sustainable house site should be edible, wherever possible. Organic vegetable gardens should include water-efficient, pest-resistant strains. Chemical pesticide and fertilizer use should be eliminated from the vegetable garden by natural prevention and maintenance practices. Southern-oriented indoor greenhouse gardens should be incorporated into the design of the house for winter food production.

Compost generated in the kitchen and/or composting toilet waste management systems of the sustainable house should be used to fertilize the gardens and food production areas.

II. Environmental Health

Human health has been proven to be inextricably linked to a variety of environmental factors, including airborne pollutants and toxins, particulates, radioactive elements, water quality, light, electromagnetic radiation, thermal conditions and sound, among others.

Sustainable housing should address these issues from a balanced and comprehensive approach in an attempt to ensure acceptable occupant health. The following section will examine the most important of these environmental health concerns.

Indoor air pollution

Canadians spend 90% of their time indoors, most of that in the home. Given that fact, and with the growing number of synthetic materials used in construction products and present in the environment in which we live, indoor air pollution has become a significant concern. Adverse health effects arising from poor indoor air quality can include dermatological, respiratory and central nervous system illness, liver and heart disease, genetic mutation (particularly birth defects) and cancer.

Indoor air pollution sources within the home can include:

☒ modern, composite wood products employed in subflooring, cabinetry, *etc.* that contain binders and adhesives that may be carcinogenic, *e.g.* particleboard (urea-formaldehyde resin);

☒ chemically treated wood products that contain the dioxins OCDD and HxCDD;

☒ insulation, *e.g.* fibreglass, UFFI, asbestos, and loose-blown;

☒ vinyl flooring made from polyvinyl chloride (PVC) that outgasses vinyl chloride;

☒ synthetic textiles that outgas formaldehyde, ethylbenzene, styrene and other pollutants, *e.g.* carpet and carpet backing;

☒ organic solvents that outgas xylene and other pollutants, *e.g.* caulking, sealants and paints;

☒ respirable suspended particulates;

☒ soil gases, particularly radon, a colourless, odourless gas present in most rocks and soils, especially granite, that emits high energy alpha particles during its decay. The alpha radiation damages the bronchial epithelium of the lungs and can cause lung cancer. Radon is the single largest environmental source of ionizing radiation. Soil gases enter homes through building materials, ground water and due to the lower atmospheric pressure within the house. Indoor concentrations vary depending on the structure of the building and the site;

☒ others.

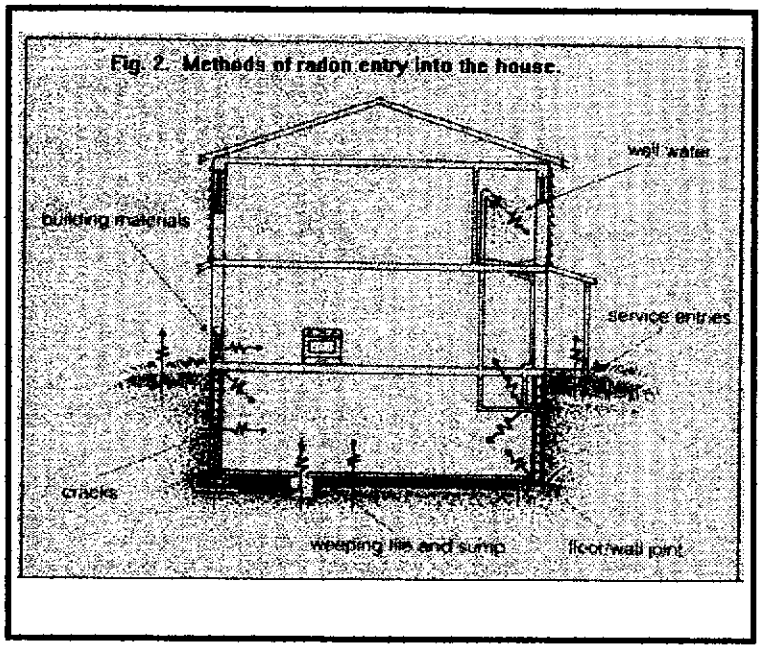


Fig. 2. Methods of radon entry into the house.

The most common contaminant type is the volatile organic compound (VOC). Many of the pollutants described above are VOCs. These are chemical compounds that contain carbon molecules and are sufficiently volatile to evaporate from material surfaces into indoor air at normal room temperatures. VOC emissions decrease with product age, *i.e.*, in most cases, outgassing of the pollutant from the product decreases as the new materials cure.

Ventilation

As envelope tightness is increased, natural filtration rates decrease. At the same time, reducing ventilation to conserve energy in airtight, superinsulated houses further increases indoor air pollutant concentrations. Both ventilation and thermal envelope heat loss should be minimized, but a proper balance of incoming and outgoing air is one essential factor to maintaining good indoor air quality.

A ventilation system is simply a network of ducts, vents and fans integrated throughout the house designed to regulate and circulate air. Ventilation is measured in a rate of air exchanges per hour (ach). The air exchange rate in a sustainable house should be no fewer than two complete air exchanges per hour, or equivalently, provide no less than $6.8 m^3$ of fresh air per person/hour. The average air exchange rate is 0.5 to 1.0 ach.

Ventilation heat loss is expressed as $Q_v = 0.36 x V x N$, where Q_v is the ventilation heat loss in W/degC. The constant 0.36 is derived from the volumetric specific heat of air (the heat required to raise the temperature of 1 cubic metre of air by 1 degree C). V is the volume of space being heated in m^3. N is the number of complete air exchanges per hour. Nonetheless, energy costs associated with air exchange can be dramatically reduced using heat recovery devices, particularly in extreme climates. These systems are called air-to-air heat exchangers, or heat-recovery ventilators (HRVs), and can significantly reduce ventilation heat loss.

In considering ventilation strategies that exchange fresh air for exhaust air in the sustainable house, designers should ensure that incoming air is brought into the house in as clean a manner as possible, that the fresh air is supplied in volumes required for acceptable occupant health, that it is thoroughly distributed to all areas of the house and that ventilation heat loss is minimized.

Many factors determine indoor air quality and there exists much interdependence of these contributing factors. While increasing ventilation rates will reduce indoor air pollution levels, this type of approach is reactive rather than preventative. Limiting or eliminating indoor air pollutant sources would be a more effective means of maintaining good indoor air quality. Changes in air exchange rates generally affect indoor air quality only indirectly, whereas the relationship between ventilation and pollutant source strength directly affects the quality of indoor air, because the relationship between pollutant (VOC) concentration as a function of source strength and air exchange rate is non-linear, *i.e.* the stronger the pollutant source the even greater air exchange required to maintain constant pollutant concentrations. Consequently, indoor air pollutant sources should be eliminated, or at least minimized, using careful planning, design, specification and construction.

Architects can promote good indoor air quality in the design stage by taking into account expected loads and likely pollutant sources and then establishing effective source control strategies. Unfortunately, determining target levels of indoor air pollutants is not an exact science. An insufficient amount of information is known about the actual health effects of most indoor air pollutants to set target, or safe concentrations. More importantly, indoor air pollutants are typically present in complex mixtures of many different chemicals that may act in additive, synergistic, independent or antagonist ways.

Thus the best option to ensure adequate indoor air quality is to reduce, *as much a possible*, indoor air pollutant sources in the design process. For example, homes in areas of high soil radon concentration can be built so as to minimize or eliminate its entry into the building, and construction materials that do not outgas volatile organic compounds (natural building products) can be specified by the architect.

Sustainable housing should ensure acceptable indoor air quality by reducing the level of contaminants built into the house, removing any indoor air pollutants at the source of production and diluting occupant air supply with fresh outside air.

Water quality

The American Environmental Protection Association has identified over 700 pollutants that occur regularly in municipal drinking water, 22 of these are carcinogenic. Some of these include ethylphenol, chlorobenzene, PCBs, chloroform and trihalomethanes. Trihalomethanes are formed when chlorine, used as disinfectant in the municipal water treatment process, combines with natural organic matter also present in the water supply. Trihalomethanes cause liver and kidney damage, central nervous system depression and are a suspected carcinogen.

Heavy metals such as cadmium, copper, iron, lead and zinc can leach into the water supply from pipes, pipe solder and other sources. Polyvinyl chloride (PVC) pipes also leach a variety of toxic and carcinogenic substances, including cancer-causing vinyl chloride, tetrahydrofuran and carbon tetrachloride among others, despite the fact that they have replaced metal pipes in many contemporary buildings because of human health concerns.

Obviously, water treatment facilities cannot remove these chemical contaminants from the municipal water supply. In addition, some of the contamination, and many synergistic reactions between chemical compounds present in the water, occurs post-treatment. Rainwater contains contaminants of similar concern and can also be acidic.

Sustainable housing should employ microbiological and chemical quality control of its drinking water supply.

Water treatment systems in the sustainable house can include activated carbon filters, reverse osmosis devices, distillation, ultraviolet irradiation and ozonation. This paper will discuss the first three. Activated carbon filters are the least expensive system, utilizing a simple process of absorption to disinfect the water supply. They are best at removing volatile chemicals, but are totally ineffective at filtering particulates, dissolved solids and microorganisms. When the carbon blocks become saturated, the filter must be replaced.

Reverse osmosis devices purify the water supply by forcing it through a selective membrane. The membrane permits water molecules to pass through it, but not pollutants (plants purify water using similar method), removing particulate matter and dissolved solids, but not microorganisms or volatile chemicals. Therefore the reverse osmosis device should be used in conjunction with an activated carbon filter. Treated water quality diminishes with the use of the device.

Distillation systems operate by an evaporation-condensation process. Boiling the water destroys microorganisms and concentrates particulates and dissolved solids that are too heavy to evaporate, resulting in a purified product. Some designs have volatile gas vents or secondary processes that enhance volatile chemical removal and are coupled with activated carbon post-filters. However, distillation is an energy-intensive process and stainless steel distillers can add aluminum to the water supply (glass systems are available).

Noise

Domestic noise pollution does not pose great risk to physical health, however, noise pollution in the urban environment can be sufficient to cause hearing impairment and also contributes to environmental stress. The structure of a building determines how well it transmits sound.

> Sustainable housing design should include thicker envelope construction to reduce infiltrated noise from external sources and acoustically insulated interior walls and ceilings to reduce noise transmission within the home.

Light

There are a number of relatively serious environmental health concerns associated with light. Ultraviolet emission from tungsten halogen lights can lead to retinal damage from prolonged direct exposure (although this activity is unlikely). Halogen lights also operate at extremely high temperatures (approximately 300 degrees Celsius). Fluorescent bulbs emit ultraviolet rays as well. While the exposure is usually intermittent, skin rashes and melanoma may occur from fluorescent lighting. The fast flicker associated with this type of lighting may additionally produce visual irritation or epileptic seizure.

Of further concern is the fact that artificial light produces a spectrum different than that produced by natural sunlight. Exposure to artificial light for long periods has been associated with decreased calcium absorption, fatigue, decreased visual acuity, hyperactivity and changes in heart rate, blood pressure, electrical brain-wave patterns, hormonal secretions and the body's natural cyclical rhythms. A related problem, known as Seasonal Affective Disorder (SAD) associates artificial light with clinical depression.

Sustainable housing design should maximize the use of natural lighting, to mitigate the adverse environmental health affects associated with limited-spectrum artificial lighting. Where artificial lighting is required in the sustainable house, it should be full-spectrum.

Electromagnetic radiation

Electromagnetic fields are induced by all electric current flow. Both thermal electromagnetic fields and lower-level, non-thermal, extremely low frequency (ELF) electromagnetic fields can induce eddy current in biological tissue. Natural background electromagnetic fields pulse at a rate of 7.83 hertz, similar to the bioelectric system present in humans. However, electromagnetic fields from 60 hertz alternating currents emit radiation that can interact with individual cells and organs to produce biological changes. The adverse bioeffects of electromagnetic radiation may be respiratory, cardiovascular, hematopoietic, immunological, neuroendocrinal or carcinogenic. Children are particularly susceptible.

The most powerful emitters of electromagnetic fields in the home include dimmer switches, photoelectric timer switches, radiant heating systems, fluorescent lights (within a six foot range), electric heaters (within a 3 foot range) and various household appliances, particularly microwave ovens, refrigerators and freezers, computers and televisions. Electromagnetic radiation can also arise from the proximity of the house to power transmission lines and all electrical wiring.

The bedroom of the sustainable house should be as electromagnetically safe as possible because most of the occupants' time is spent here.

> Electromagnetic radiation within the sustainable house should be reduced by the use, or specification of shielded electrical wiring, climate-responsive heating and cooling systems, alternative energy sources that produce a lower voltage electricity and items that minimize total electricity demand, *e.g.* windows and skylights that reduce need for electrical lighting.

> Sustainable housing should attempt to be self-sufficient of the municipal sewage and solid waste disposal infrastructure.

III. Waste Management

Three types of waste are produced within the house: wastewater, organic waste (kitchen compost), and solid waste. Wastewater contains two distinct components: blackwater, containing sewage from toilet fixtures, and greywater, from all other non-toilet plumbing fixtures and appliances within the home. The sustainable house should reduce, and where possible, eliminate the production of each type of waste.

Wastewater

A traditional classification of wastewater disposal systems, based on the disposal process, would include infiltration, removal, destruction and decomposition types. Infiltration is the absorption and dispersion of sewage in the soil and groundwater, as in a septic system. It is the oldest and most widespread method. During the infiltration process, waste is fermented in a pit or container and then allowed to infiltrate the soil. The capacity of soil to absorb the sewage is critical to an efficient process, therefore the soil must be sufficiently porous and sufficient area must be allowed for the dispersal of effluent.

The removal method involves the transportation of sewage to be disposed of in off-site sewage oxidation ponds, bodies of water or for further processing. In most cases, the removal method requires large volumes of water to transport the sewage through a sewer system. The subsequent process is predominantly chemical.

Destruction is a method whereby the sewage is reduced by combustion. The waste can, in some instances, be used as a fuel. Incinerating toilets employ the destruction method.

Decomposition of sewage is characterized by microbiological (aerobic or anaerobic) breakdown of the waste into a nutrient-rich humus. It is a very efficient waste disposal process that destroys pathogens and produces a useful end-product. Composting toilets are a sustainable alternative to conventional flush-toilet systems.

Obviously, the most employed method in the urban setting is the removal process. However, the economic and environmental costs of purifying wastewater in conventional water-borne municipal sewage treatment systems are significant. More importantly, these costs represent a misuse of energy and resources as wastewater is composed of only 1% sewage, and the costs are, primarily, those associated with purifying the transporting medium, rather that the waste itself.

Conventional sewage treatment facilities employ environmentally adverse chemicals in their process, fail to remove toxic metals from the waste and produce a toxic sludge by-product that must be landfilled, incinerated or disposed of in some way. Evidently, non-chemical, *in-situ* sewage disposal would provide a far more sustainable alternative. There exist two options for processing wastewater in the sustainable house. These are a) a combination of greywater recycling and blackwater composting, or b) solar aquatics, an "eco-engineering" wastewater treatment system, whereby aquatic plant and animal organisms process the wastewater producing a potable end-product.

Greywater recycling & blackwater composting

Greywater contains fewer nutrients, disease carrying organisms and pollutants than blackwater and can consequently be reused in garden irrigation systems. However, the composition of greywater may still be hazardous to plants and soil, or may be produced in volumes and at frequencies not matched to the requirements of the garden, for example, during the winter. Plants that require low pH levels would not grow well with the use of a greywater recycling system due to the water's high sodium and chloride concentrations. Nonetheless, plants that are tolerant to the eventual build-up of salts and alkaline conditions can grow well with greywater reuse. In fact, the best application of greywater is on lawn. Greywater reuse systems can also be employed in greenhouse gardens.

Blackwater can be composted in composting toilets with substantial economic benefit. Not only does a composting system reduce household water demand, it produces nutrient-rich fertilizer as an end-product. The original composting system, the Clivus-Multrum mouldering toilet, was invented by a Swedish engineer in 1938 by the name of Rikard Lindstrom. It was patented in 1962 and first commercially produced in 1964. The Clivus-Multrum has been in production in the United States since 1974. Mouldering, a type of decomposition, requires longer-term storage (two or three years), due to the cooling effect of introduced air. The Clivus-Multrum system consists of a large chamber (160 cu feet) provided with air ducts and a vent pipe and a sloped bottom to allow periodic removal of the compost. The process also requires organic wastes from the kitchen or garden to be mixed with the sewage to produce high-quality compost.

The double-vault composting toilet (DVC) is another type of composting system, that utilizes two separate decomposition chambers rather than one. Double-vault composting toilets are defined as having three characteristics: a) the sewage is deposited in one of two vaults, compartments or pits, which are used alternatively, b) while one vault is use, the sewage is retained and composted in the other for an extended period of time, and c) when the composting period is over, the humus is removed from the vault for use as fertilizer. Thus DVCs differ from the multrum (a continuous composting toilet) as multrums consist of a single compartment with sloping bottom and baffle to allow periodic removal of composted material. Not all DVC toilets require ventilation, or that organic refuse be added. Retention times vary from a few months to a few years.

Solar aquatics

Both grey and blackwater can be ecologically treated, *in-situ*, by a solar aquatic wastewater treatment system. Designed by Dr. John Todd, a Canadian biologist, this "ecologically engineered" system uses solar energy, plants and animals to produce potable water from wastewater. It is a system designed to enhance the natural biochemical responses of certain plant and animals species to human organic waste. The solar aquatics system must be located in a greenhouse that insulates the process while allowing sunlight, essential for photosynthesis, to be absorbed by the plants. The solar aquatic process involves a number of steps, most steps of the process being distinct ecosystems unto themselves. These are:

☒ first, the wastewater flows from toilets and all other plumbing fixtures and appliances into anaerobic digestion tanks where preliminary decomposition by anaerobic bacteria occurs;

☒ from the anaerobic phase, the wastewater flows into another set of tanks where it is aerated to suspend solid materials and facilitate the decomposition of organics by aerobic bacteria; at this stage, nitrogen-fixing microorganisms also convert toxic ammonia into nitrite and then nitrate;

☒ the wastewater then flows into a series of clear glass cylinders, or silos, containing additional bacterial populations, shellfish and various aquatic plants; algae growing at the edges of these cylinders metabolize the nitrate; zooplankton and snails present in the cylinders feed on the algae populations;

☒ from the cylinders, wastewater flows to a small pool containing fish (striped bass and/or tilapia) that also feed on the nitrate-consuming phytoplankton, and water hyacinths that absorb toxic metals present in the water;

☒ from the pool, wastewater is pumped into hanging pots, containing mosses and other plants through which the water is filtered further;

☒ the wastewater then flows into artificial, engineered marshes; the marshes are essentially plastic troughs lined with gravel and cultivated with wetland plants; anaerobic bacteria in the gravel bed convert any remaining nitrates into nitrogen gas; remaining solids are filtered through the sand and stone where they are decomposed and taken up through the root systems of the marsh plants; in addition to removing remaining nutrients, the wetland plants (bulrushes, blueflag, umbrella plant) also absorb heavy metals and other toxic chemicals that may still be present in the water;

☒ finally, the water is disinfected by ultraviolet radiation.

The water output from the solar aquatic system is clear, sludge-free and safe. In fact, it is cleaner than municipal tap-water. Solar aquatics completely removes 14 out 15 EPA-classified priority pollutants (and 99.9% of the 15th) from wastewater. Except for the pump required to move the wastewater from the plumbing fixtures to the greenhouse system and the pump needed to move the water from the pool to the hanging filter pots, the solar aquatic process is also entirely non-mechanical. Gravity moves the wastewater from one step of the purification process to the next, as the effluent enters at the top of each tank and flows out the bottom via a standpipe. Consequently, solar aquatics is not an energy intensive process. It is a truly sustainable wastewater treatment process.

Solar aquatic systems are currently in place in the Ecology Centre at the Toronto Board of Education Boyne River Natural Science School in Shelbourne, Ontario and in The Body Shop corporate and production headquarters in Toronto. A solar aquatic wastewater treatment system was also integral to one of two winning designs in the Canada Mortgage and Housing 1993 Health Housing Design Competition. Unfortunately, due to municipal by-laws and other regulatory and beaucratic obstacles, none of the systems are currently operational.

Organic waste

All household and yard organic waste generated in the sustainable house should be composted, on-site, to maximize nutrient recycling and reduce waste disposal requirements.

Compost produced from organic waste should be used in the house's decorative and food-producing gardens. For sites that do not permit backyard composting, or for compost production during winter months, vermicomposting should be employed.

Vermicomposting is simply composting indoors, with red worms in plastic bins. Red worms are very efficient decomposers, illustrating a 1:1 weight to product ratio. They are also prolific. The finished compost can be harvested in as short as two months.

Kitchen design in the sustainable house should facilitate organic waste collection and storage for backyard, greenhouse or vermi-composting.

Solid waste

Any solid waste that remains after this process must be landfilled, however sustainable housing will significantly reduce the volume of waste flow off-site by such means as *in-situ* food production.

Solid waste management strategies in sustainable housing should follow the 3R hierarchy: reduce, reuse and recycle. Household hazardous waste should be eliminated entirely from the sustainable house.

IV. Water

Canada is confronting a major water crisis, a shortage that could leave North America unrecognizable. Canadians have been so lulled by their own mythology, their vision of

> a land of countless lakes and a myriad of untamed rivers, that they have not yet noticed the danger, let alone started to avert it (qtd. in Grady 1993).

Water is an essential, but expensive resource. Current water economy, based on the supply-demand theory, illustrates the fact that society faces an undeniable water "shortage", that is the result of two anthropogenic causes: population growth and industrialization. These factors have caused an upsetting of the natural water balance as maintained by the hydrological cycle. Inefficient or wasteful water use, and water pollution, particularly, have been responsible for diminishing water resources.

On a per capita basis, Canadians are the second largest users of water in the world. The average Canadian uses 350 litres of water a day, almost all of that in the home. Coupled with unsustainable water use, is unsustainable wastewater production. For example, the average toilet produces more than 20 litres of wastewater per flush, of which less than ⅓ of a litre is actual waste, and during an average day, in an Ontario Building Code house, 164 litres of water goes down the drain of a bathtub. To alleviate the concerns associated with water use within the conventional home, three principles should be applied in the design of sustainable housing: water conservation, rainwater recovery and water reuse.

Conservation

The most effective means of reducing demand for clean water and reducing the production of wastewater within the sustainable house is to maximize the efficiency of water use.

Water conservation can be achieved by the use of flow restrictors, water-efficient appliances and atomized water devices. Atomization is defined as the mechanical separation of a bulk liquid, where droplet control is achieved by varying nozzle details and pressure. The optimum range of atomization for a shower or bath spray, for example uses fast-moving small droplets for maximum coverage with minimum water use. Ranges of atomization are possible, depending on the size of the water droplets. Sprinkling is defined by very coarse drops, of 1000 micron diameter or greater. Spraying is characterized by coarse drops of between 100 and 1000 microns in diameter. Fine drops, of 10-100 microns in diameter are typical of misting. Nebulizing flows contain very fine drops of less than 10 microns in diameter.

Bathroom water use accounts for almost 75% of all water used in the home. Forty percent of the average annual water consumption of a North American family is used for toilet flushing. Each flush requires between 22½ and 31½ litres. Water conservation in the bathroom can be achieved by the use of:

☒ low-flush or ultra low-volume (ULV) toilets; some use as little as one cup of water per flush and can reduce total household water consumption by over 30%; these can be directly vented to eliminate odours;

☒ aerator/atomized shower heads that can reduce water use in the shower by more than 60%;

☒ restricted flow taps.

The kitchen and utility areas of the sustainable house should feature similar water-efficient devices. These being:

☒ restricted flow taps that can reduce total water use in the kitchen by over 60%;

☒ water-efficient washing machines, that feature front-loading and water recycling and similarly efficient dishwashers that also conserve significant volumes of water.

Rainwater recovery

> Sustainable housing should be self-sufficient of municipal water supply.

Rainfall offers the homeowner a natural, reliable and sustainable supply of water, while limiting the amount of water run-off from the property that must be managed by a municipal sewage infrastructure. A rainwater recovery system catches roofing run-off and is thus directly related to roof size. Rainwater recovery can provide total year-round household water requirements if properly practiced.

To be completely self-sufficient from the municipal water supply, sustainable housing design must match total water intake with total water consumption. To determine water *supply* from a rainwater recovery system, the following must be calculated:

1. *corrected annual rainfall* (this figure should be an average of the three driest consecutive years on record so as to eliminate over-estimation of average rainfall);
2. *catchment area* is the area of the roof (for a flat roof), or the area of the roof in its planar form (for a pitched roof), then;
3. *rainwater collection* (L/yr) = *annual rainfall* (mm) x *catchment area* (m^2) x 0.9 (where, 1 millimetre of rainfall is equal to 1 litre of collected water per square metre of catchment area, and water loss must be assumed due to evaporation and spillage at point of collection at approximately 10%).

Collected rainwater should be stored in two cisterns. The primary storage cistern should be large enough to contain 25% of estimated annual yield, should have overflow control and be lined with lime to neutralize the acidity of rainwater. The second cistern should be located at the highest point in house (in the rooftop greenhouse). Water should then flow to the house's plumbing fixtures by the force of gravity rather than by pump.

Collected rainwater intended for drinking purposes should be purified to remove both chemical and microbiological contaminants. Loss of purified water through leaks, burst pipes and faucets must be accounted for (approximately 13% of total post-collection supply). Water conservation and water recycling are essential practices for the rainwater recovery system to be sufficient for total household needs.

Reuse

> Sustainable housing should reuse greywater, or alternatively, the product of the solar aquatic wastewater processing system to ensure the sufficiency of the rainwater recovery system and the sustainability of water resources.

V. Construction and Materials

All housing consumes energy and resources by necessity. However, sustainable housing attempts to minimize the consumption of resources, particularly those that are not renewable. To achieve this goal, the design and construction of a sustainable house requires a full life-cycle assessment of building materials and resource utilization. A life-cycle assessment of the environmental impact of resource consumption includes an evaluation of supplementary resource consumption and energy use at every step of a product's development, from the extraction of a raw material from its resource base to the final disposal of the material.

The use of green building materials (products with low, or reduced environmental impact), sustainable construction processes, and fundamental design principles that maximize resource efficiency all reduce housing's consumption of resources.

Green building materials

> Construction of the sustainable house should employ green building materials.

Green building materials are those that have low, or relatively lower, environmental impact based on the following conditions:

☒ raw material source and resource extraction process; products that can be obtained with minimal environmental damage should be emphasized;

☒ recycled content; building products with recycled content necessitate a reduced consumption of virgin resources;

☒ durability; building materials with maximal lifespans should be specified;

☒ toxicity; natural, non-toxic, non-outgassing products should be emphasized (these are often inert materials that contain metal, glass or concrete that are also easily recycled);

☒ recyclability; how readily a product can be recycled given current technologies;

☒ embodied energy; the designer of the sustainable house should make choices relating to materials selection that optimize energy use at all stages of product development, manufacture and distribution, including the extraction of the raw material (or collection of the used resource), the transportation of the raw material to the manufacturing location, the manufacture of the product (or processing of the recycled material), the dissemination of product information, the distribution of the product to the construction site and the construction process.

Build Green products

The *Build Green Program,* a joint initiative of the Greater Toronto Home Builders' Association (GTBHA) and ORTECH, identifies building products that contain post-industrial and post-consumer recycled content, are recyclable and are manufactured using sustainable construction processes. For example, Marmoleum high-traffic flooring is made from linseed oil of the flax plant, natural pigments and resins, wood and limestone. Some other *Build Green* products include:

Rustic shingle, Classic Products Incorporated

Roofing shingles are manufactured from alloy that is 98% post-consumer recycled aluminum from used beverage containers. The aluminum reflects radiant heat to reduce attic heat gain. Shingles are extremely lightweight and durable and can be installed over an existing roofing system, eliminating the need to landfill the old roof and increasing the building's thermal mass.

Everlasting & Enviro-Floor carpets, Triathlon Carpets
100% of the carpet yarn is extruded spun from recycled polyethylene terephthalate (PET), primarily derived from post-consumer recycled soft drink bottles. The carpets do not have formaldehyde finishes. The manufacturing process eliminates hazardous waste and uses less water than conventional processes.

Dura carpet undercushion, Dura Undercushions Limited
A carpet underlay containing 80% post-consumer recycled ground rubber tires.

Canfor Finger Jointed Studs of FJS, Canadian Forest Products Limited
Studs are made from "off-cuts" left over from the production of longer lengths (8 feet to 18 feet) and are joined together to form a single board. Studs produced are stronger than conventional studs and are also straighter.

Medium density fibreboard, Can Fibre
Medium density fibreboard panels are produced from 100% recycled wood fibres, non de-inked newsprint, cardboard, telephone books and tetra-pak juice containers.

Sustainable construction processes

As much a 2.5 tonnes of waste is produced in the construction of a typical new house in Canada. The average single-family house built in Canada in 1990 used lumber equivalent to 1 acre of forest, 10 per cent of which ended up in a landfill. Construction processes that minimize waste and optimize resource use include:

☒ proper management of construction waste, for example, masonry, wood, corrugated cardboard, metal and drywall recycling, and the appropriate disposal of toxic and hazardous materials;

☒ efficient use of building materials, for instance, the use of leftover framing wood in non-structural applications, and the proper handling and storage of materials to avoid damage;

☒ use of standard sizes and lengths to minimize wastage;

☒ materials salvage and reuse.

Design

The sustainable house should reduce material requirements through optimized building size and form.

Building size and form play a major role in determining the amount of resources required in the construction and operation of a house. Obviously, smaller, more compact designs require fewer materials. In smaller house designs, volume to surface area ratios can be maximized, resulting in increased interior space relative to the size of the building envelope.

The bulk of all resources incorporated into the house are contained in the structural elements of the building, thus the sustainable house should be typified by structural assemblies with maximum life expectancies so as to minimize both resource consumption and the need to adopt disposal and replacement strategies.

Vernacular design, characterized by specific styles, materials and construction techniques, arises from learned certainties about efficiency and durability in local ecosystem and microclimate conditions, thus the sustainable house should employ vernacular design to maximize resource efficiency and durability.

Sustainable housing design should additionally take into account the ease of maintenance and repair of building components during the regular occupation and operation of the house. Design that maximizes ease of maintenance and repair of critical components of the building while maintaining resource efficiency should be employed.

VI. Energy

Energy use in housing accounts for 20% of Canada's total energy consumption. Energy consumption within the home is composed of space heating and cooling (67%), lighting and appliances (18%) and water heating (15%). Clearly, the largest opportunity for energy savings is available in the first energy-use category. By improving the thermal envelope of a house and the performance of its heating and cooling systems, total energy demand can be significantly reduced. Minimizing the amount of energy consumed in the operation of lights, appliances and domestic hot water systems can further reduce energy demand. Once energy conservation and energy efficiency have been implemented, renewable energy systems become viable alternatives in the sustainable house.

Sustainable alternative energy systems

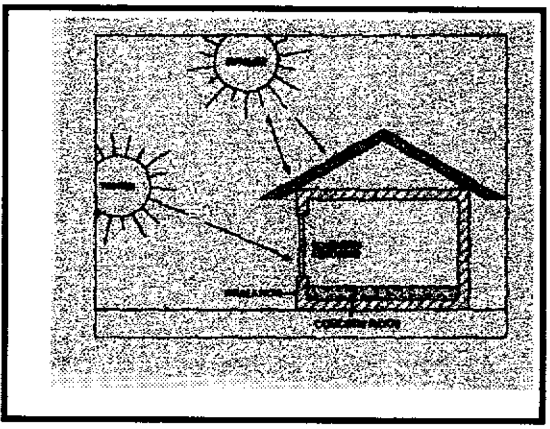
Sustainable housing should be self-sufficient of the electrical grid and meet it energy needs by means of efficient, alternative energy strategies.

Sustainable alternative energy systems viable within the urban setting include: passive and active solar gain, photovoltaics and biomass energy.

Passive solar gain

> Now in houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer, the path of the sun is right above the roof so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun, and the north side lower to keep out the cold winds (Socrates, 360 B.C.).

Passive solar heating strategies are based on orientations of the house that optimize solar heat gain, thermal storage materials that reduce temperature fluctuations and distribution systems that circulate the heat throughout the house with little or no external power supply. A passive heating system is nothing more than the house itself functioning as a collector of solar thermal energy.



Passive solar design should:

☒ maximize south-facing glazing for optimum solar gain without overheating, by maintaining the long axis of the house in an east-west direction and employing a roof overhang;

☒ minimize polar exposures;

☒ optimize the glazing to frame ratio, using larger windows in lieu of several smaller units;

☒ size the structure's thermal mass to maintain temperature fluctuations with occupant-acceptable ranges.

A *direct passive solar gain* system can be divided into five elements:

1. The collector. An area of transparent/translucent glazing located on the southern elevation (oriented to solar south ± 30 degrees) that is vertical or sloped. The collector admits solar radiation onto the absorber.
2. The absorber. The surface exposed to solar radiation entering through the collector. It converts solar radiation into heat, that is then reradiated, conducted away or transferred to the indoor air.
3. Storage. A high-mass medium that holds heat transferred to it from the absorber. Adequate storage volume is required to contain all absorbed solar radiation. The absorber and storage are often the same medium, *e.g.* masonry or ceramic tiles.
4. Distribution. The method by which the heat is delivered to the building from the thermal mass storage, by natural means, *e.g.* reradiation or natural convection, or by mechanical means, *e.g.* fans or pumps.
5. Heat regulation. An insulating control mechanism to reduce heat loss through the collector and maintain relatively stable temperatures within the house.

Indirect passive solar gain employs a thermal mass immediately between the collector and the conditioned area. The thermal mass, often a masonry (trombe) wall, collects and absorbs the solar radiation at the same rate as the glazing but delivers delayed radiant heat energy due to the lag time of conduction through it. Trombe walls are non-load-bearing interior walls.

Thermal storage is required with both types of passive solar gain as solar radiation is an intermittent energy source, whose availability is affected by the daily solar cycle, seasonal variations and weather conditions. Choice of a storage material should be based on the following criteria, dependent on a material's thermal properties in the operating temperature range:

☒ storage capacity per unit mass and volume;

☒ capacity to regulate uniform temperatures;

☒ durability;

☒ capability to charge and discharge heat with maximal heat input/ouput rates but minimal temperature gradients;

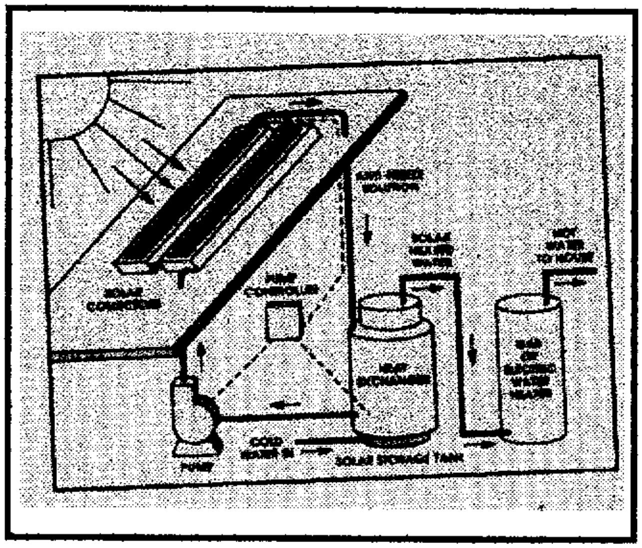
☒ colour; thermal mass of lighter colour will reflect sunlight at a greater rate, more uniformly distributing the transmitted solar radiation within the conditioned space before it is absorbed, but also increasing the opportunity for reradiation through the glazing.

The optimal location of a thermal mass is at the floor level.

The roof overhang in a passive solar energy systems operates as control structure. During the summer when solar radiation is incident at a large angle, heat gain is impeded by the overhang. During the winter when solar radiation is incident at a much smaller angle, passive solar heat gain can occur.

> Passive solar heating can meet 100% of the space heating requirements of a sustainable house with a relatively airtight structure, when employed in conjunction with energy conservation measures.

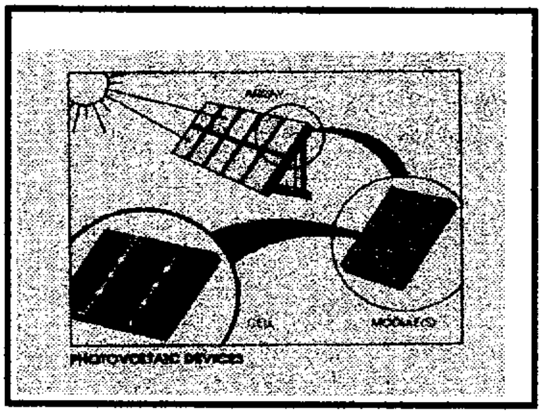
Active solar gain



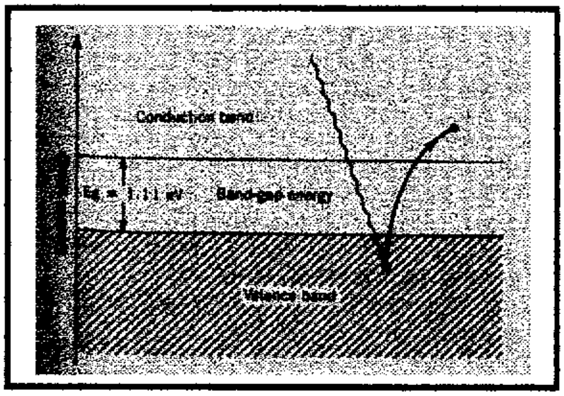
Active solar heating differs from passive solar heating in that it involves the mechanical transportation of collected solar energy to a storage or distribution system for use. Active solar heating employs flat-plate collectors located on a south-facing rooftop that capture the sun's energy in a heat-transporting fluid, usually water, that is pumped through flow passages from the rooftop to a storage tank. Heat absorption efficiency depends on the glazing on the collector plate and the thermal resistance between the flow passages and other materials in the collection system. Expected demand must be matched with size of collector area, pump, storage volume and piping diameter.

Active solar gain, with a supplementary hot-water heater, should supply hot-water needs of the sustainable house.

Photovoltaics



Photovoltaic systems convert sunlight into direct electrical current. A photovoltaic array is a mechanically and electrically integrated assembly of semi-conductor modules designed to provide a specified amount of DC power. Flat-plate photovoltaic arrays can be mounted on the roof of a house.



Photovoltaic systems generate electricity when a light photon collides with a silicon atom in a semi-conductor cell, freeing a valence electron from the atom and allowing it to move through the semi-conductor. As a result of an electric field, permanently created at a positive-negative junction of two dissimilar sections of the semi-conductor material, freed electrons are separated from the silicon atoms before they can recombine and an electrical current is generated. The current flows when an electric load is connected between metal contacts on the two surfaces. The strength of the current is directly proportional to the intensity of the solar influx.

To avoid diurnal variations in power to the load, photovoltaic arrays are used as battery chargers so that stored energy can be used later. Due to variability in daily insolation and the limited efficiency and capacity of photovoltaics, they cannot realistically operate as a standalone system, but should be incorporated into multiple alternative energies system, *e.g.* co-generation.

Sustainable housing should employ a photovoltaic energy system, in combination with a secondary energy supply, for all its electricity needs.

The practice of energy conservation and energy efficiency are also essential to a successful photovoltaic energies strategy.

Biomass energy

Biomass energy is produced from natural organic matter, quite often wood products. Biomass combustion can heat water or produce steam to drive a turbine and has applications in co-generation systems. For example, biomass energy can supplement active solar water heating.

The thermopile, an electricity-generating biomass heat engine can supplement a photovoltaic array as a back-up strategy in a multiple alternative energies system.

Biomass energy, a renewable energy source, should be utilized in the sustainable house as part of a co-generation strategy.

Energy conservation

Sustainable housing should attempt to maximize energy conservation through minimal envelope heat loss in the winter and minimal envelope heat gain in the summer.

Mechanisms of heat loss

Design heat loss is a function of the surface to volume ratio of the building, the thermal resistance of the building envelope and the natural air leakage rate of the building. Methods of heat loss include:

☒ conduction; the transfer of thermal energy through a medium by direct molecular interaction, where the energy flows from high to low temperature regions (insulators are poor thermal conductors that retard heat transfer);

☒ convection; the transfer of thermal energy by fluids and gases in contact with solid surfaces, for example, between air and some element of a building structure, where the rate of heat transfer varies with the temperature differential between the two substances;

☒ radiation; the transfer of thermal energy by electromagnetic waves (radiant heat energy does not require a medium to move through), *e.g.* solar radiation;

☒ air exchange; the loss of warm air from the interior of the building to its exterior by means of infiltration (unintentional heat loss around windows, doors, *etc.*) or ventilation;

Sustainable housing should make use of materials and techniques that have high resistance to heat transfer.

Insulation

Insulation is composed of materials that have high resistance to conductive heat transfer because of small cellular voids in their structure that slow molecular interaction. Typical insulations are highly processed materials designed to be used be with conventional construction techniques, *i.e.* to fill large structural cavities in stud-frame or concrete-block building. Insulation also reduces radiant heat loss by reflecting radiant heat.

The air-vapour retarder, installed on the interior side of insulation to protect the insulation and the structure of the house from moisture damage and prevent uncontrolled air leakage, is an essential part of the insulation process. Super-insulation of all heat loss areas within the house, including external and internal walls, the attic, roof, basement, windows and doors is very effective at reducing envelope heat loss and should be incorporated into an overall energy conservation system. Insulation of the thermal envelope may also be achieved by the use of insulative building materials in the exterior finish.

Thermal conductivity of insulation varies with type of material and the area and thickness of the insulation. Conductive heat flow is inversely proportional to the thickness of the insulation. Thermal conductance through an insulation is expressed as a U-value. Thermal resistance of the insulation to heat transfer is expressed as an R-value.

> The sustainable house should be insulated with high R-value insulation in all major heat loss areas to reduce heat transfer through the thermal envelope.

Low-emissivity glazing

Low-emissivity window coatings are invisible, ultra-thin, infrared-reflecting silver treatments on a glazing surface. They are rendered transparent by visible-spectrum anti-reflection coatings (similarly used on camera lenses). Ordinary glass does not act as a radiation trap, only as a convection trap, thus conventional windows are very poor thermal insulators. Heat loss occurs through windows as thermal energy is conducted through the glass pane, or in a multi-glazed unit, as it is conducted through the inside glass, transferred by convection across the airspace and then conducted again through the outside glass. Low-emissivity glazing reduces heat loss by conduction and convection.

Short-wave solar radiation is transmitted through the glazing into the house where it is converted into long-wave infrared radiation that we feel as heat. The long-wave thermal radiation is reflected and reradiated from objects inside the house, but cannot pass back through the low-emissivity glazing, because of its wavelength. The low-emissivity oxide coating is selectively reflectant to radiation of different wavelengths. Long-wave infrared thermal radiation cannot pass through the coating.

Emissivity values range between 0 and 1. Lower emissivity coatings reflect more infrared light. Surfaces with E-values at or below 0.20 are considered low-emissivity. Low-emissivity double-glazed windows can reduce night-time radiant heat transfer across the air gap by 90%. However in air-filled glazings, heat is still transferred by convection across the airspace between window glazings. Yet if the trapped air is replaced with a more viscous and insulating inert gas such as argon or krypton, heat transfer is further lowered.

All glazing within the sustainable house should employ low-emissivity, triple-glazed, krypton gas-filled windows that offer the highest resistance to heat transfer.

Heat recovery

Heat recovery ventilation technology (air-to-air heat exchangers) can recover 70% of the heat from stale, indoor air when it is vented to the outside. Waste heat recovered from household appliances can also be recycled for space heating purposes.

Building design

Energy conservation can be implemented in the design of the sustainable house by:

☒ designing for the lowest possible exterior surface area to floor space ratio, for example, by reducing the number of exterior walls through row or stacked housing;

☒ reducing the thermal bridge across the building envelope by minimizing excess framing lumber and isolating the foundation from the surrounding soils;

☒ installing greenhouse air-lock or vestibule entrances and doors and windows with low infiltration rates;

☒ reducing the need for artificial lighting by employing properly located skylights and windows and reflective interior finishes;

☒ constructing double-envelope houses;

☒ installing automated, intelligent building controls, *e.g.* motion sensors;

☒ employing temperature buffer zones;

☒ designing structural windbreaks.

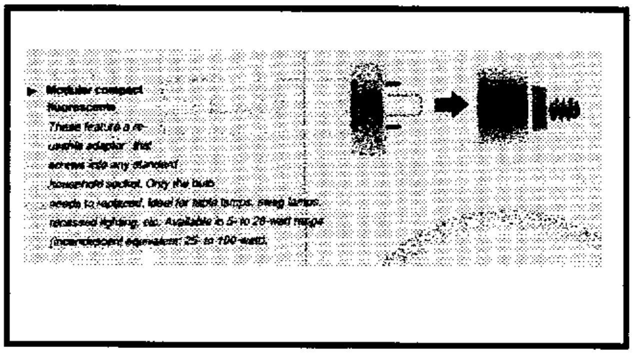
Energy efficiency

> Sustainable housing should utilize energy-efficient heating and ventilation systems, lighting and appliances.

Energy efficiency within the sustainable house can be achieved by the use of:

☒ fluorescent lighting; compact fluorescent bulbs use 75% less energy than incandescents and have a lifespan ten times longer (lower wattage fluorescent bulbs can be used in lieu of higher wattage incandescents);

- ☒ solid-state dimmers;
- ☒ illuminance-regulated task lighting;
- ☒ energy efficient dishwashers, washers, dryers, refrigerators and freezers that can reduce energy consumption by more than 15% (energy efficient dishwashers also use less hot-water).



▶ **Modular compact fluorescents**

These feature a re-usable adaptor that screws into any standard household socket. Only the bulb needs to replaced. Ideal for table lamps, swag lamps, recessed lighting, etc. Available in 5- to 28-watt ranges (incandescent equivalent: 25- to 100-watt).

VII. Affordability and Economic Viability

For sustainable housing to be a practical alternative to conventional housing, it must be affordable to the homeowner and economically viable to the housing industry. Sustainability will save the homeowner money in the long-term for a few fundamental reasons. First, the sustainable house is smaller, by necessity, than its typical suburban counterpart. Instead of wasting space and resources, it makes efficient use of materials, natural resources and space. Second, although the first-time, or start-up costs associated with sustainable housing may, in certain cases, be greater, the virtual elimination of utility bills means that operating costs are trivial.

Traditionally, the housing industry has been slow to accept new technology and ideas. It is unlikely that sustainable housing will be adopted, in its entirety, in a expeditious manner either. Additionally, there exist a number of municipal zoning by-laws and other beaucratic obstacles that would currently inhibit the full realization of the sustainable house by the housing industry. Nonetheless this sector will also benefit by accepting the concept of sustainable housing. By employing more conservative and less wasteful construction techniques, builders will save money. As well, the use of recycled resources as opposed to virgin resources in a multitude of building products should eventually result in less expensive products.

The affordable sustainable house is a reality. Not only does it make good economic sense, but when the environmental costs of conventional housing are included in the equation of value, sustainable housing is an option society cannot afford *not* to choose.

References[†]

Canada Mortgage and Housing Corporation. 1993. Healthy housing: a guide to a sustainable future.

Grady, Wayne. 1993. Green home: planning and building the environmentally advanced house. Camden House Publishing, Camden East.

[†] This list of references ascribes only a very few materials referenced directly in this paper. A multitude of other resources were referred to in the researching of the two essays. A complete list of resources is attached in *Appendix A: The Sustainable House Resource Database (Lotus Approach 2.1)*.

Appendix A

The Sustainable House Resource Database

Included with this paper is a 3½ inch floppy diskette. The disk contains database files generated in Lotus Approach 2.1, a relational database program. The database is a compilation of all the resources that I used, in some capacity, when researching the topic of sustainable housing for the Environmental Resource Science reading course at Trent University. There area total of 48 records in the database. Lotus Approach supports all popular database formats, so that the files included on this diskette may used with virtually any relational database software on the market. A hard copy of the database viewform is included in this appendix.

Keyname
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Resource Type
Book

Title

Publisher

ISBN

Address

Pages

Year/Issue

Phone#

FAX#

Comments