THE UNIVERSITY OF MANITOBA

SOLAR ENERGY FOR EXISTING HOUSING

BY

ROBERT W. WALFORD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR

THE DEGREE OF MASTER OF CITY PLANNING

WINNIPEG, MANITOBA

AUGUST 1983

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Robert W. Walford

A thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF CITY PLANNING

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ACKNOWLEDGEMENTS

The author wishes to thank the Canada Mortgage and Housing Corporation for its financial support in undertaking this thesis through its scholarship program.

August 1983

Winnipeg, Manitoba

ABSTRACT

This thesis examines the potential for solar energy systems as a heating source in existing residential areas. The environmental impacts of solar energy vs. fossil fuels are evaluated, along with solar energy's potential contribution to gross energy supply. Generic types of passive and active solar energy systems are outlined in terms of their operational principles, and criteria for the retrofit of solar energy systems to existing housing are evaluated. Through the use of a case study approach to two Winnipeg residential areas, these retrofit criteria are evaluated in terms of existing housing stock, street orientation, vegetation, housing age and insulation levels, and present mode of heat supply. Physical and legal mechanisms to protect solar access in residential areas are reviewed, leading to certain policy recommendations. Methods to evaluate the financial suitability of solar energy systems are presented, and positive and negative factors affecting the economic viability of solar energy systems are analyzed. Financial incentive programs to increase the use of solar energy are then evaluated, leading to certain policy recommendations. The thesis summary outlines the prospects for solar energy use, as an outcome of the case study and the criteria for financial evaluation.

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INTRODUCTION

The purpose of this thesis is to examine what contribution solar energy can make to residential heating, in particular the retrofit application to existing housing versus new subdivision housing. The accompanying diagram outlines the basic structure of this thesis:

Chapter 1: Solar Energy as a Resource

Chapter 2: System Types - Active and Passive

Chapter 3: Physical Evaluation

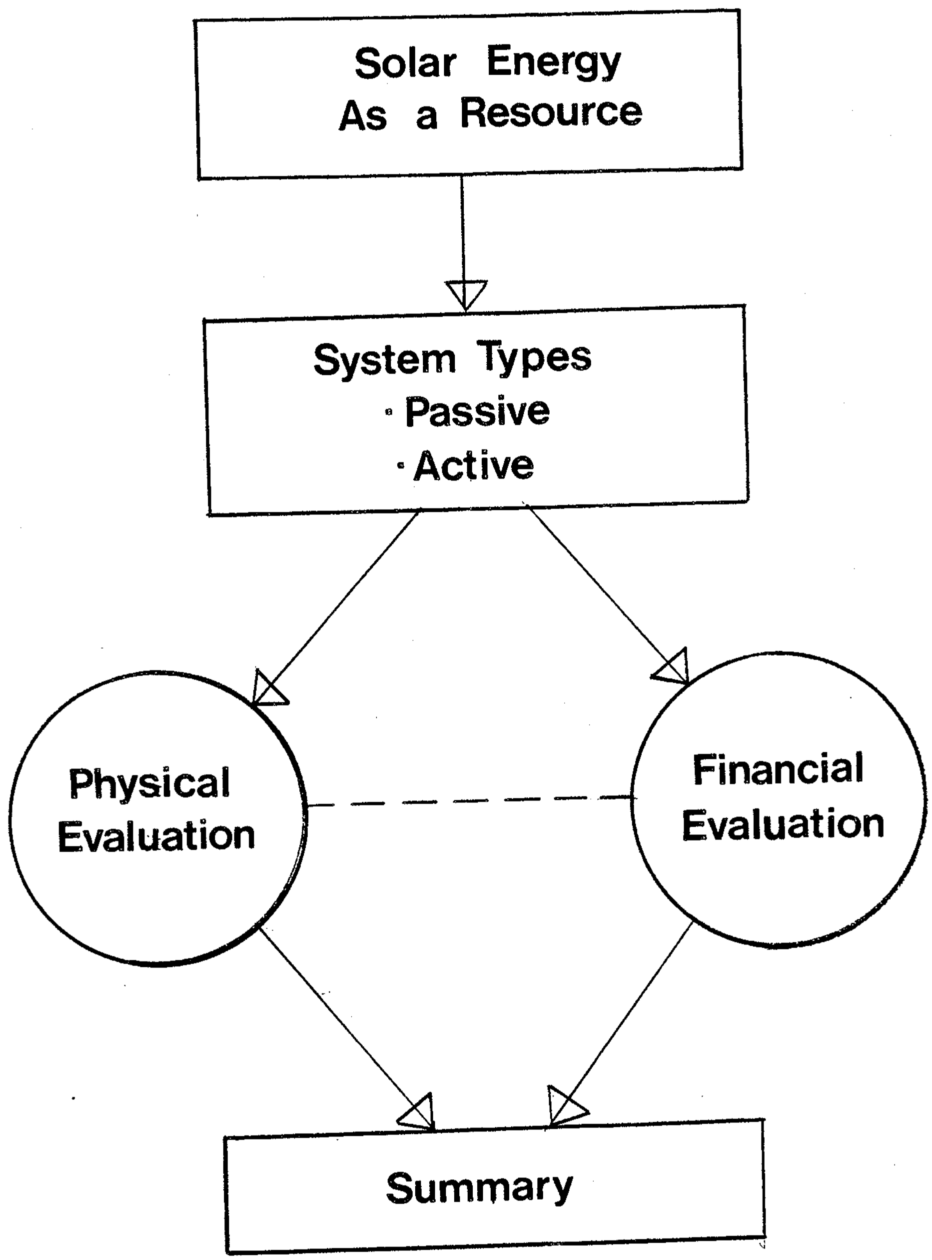
Chapter 4: Financial Evaluation

Chapter 5: Prospects for Solar Energy

Chapters 1 and 2 are the result of an extensive literature search on the environmental, socio-economic, and technological aspects of solar energy use for space and water heating. Chapter 3 incorporates a case study of two existing areas in Winnipeg, the analysis and evaluation of case-specific data, a review of various legal mechanisms to protect solar access, and specific policy recommendations arising from the case study. Chapter 4 analyzes two methods of financial evaluation that have been outlined in government literature for solar energy systems, evaluates the use of financial incentives, and identifies financial policies that would promote the residential application of solar energy. The summary presents the prospects for solar energy in terms of a mathematical model by another researcher and in terms of projections for fuel market share by solar energy.

Prior to the start of Chapter 1, it would be useful to present a synopsis of the thesis content in order to clarify the scope of this

SOLAR ENERGY FOR EXISTING HOUSING



STRUCTURE

work. The first chapter reviews the historical context of solar energy in terms of agricultural, residential and industrial applications. Solar energy is defined in terms of its physical characteristics and the types of technologies that it can be applied to. The objectives of increasing energy supplies and reducing environmental impact are reviewed in terms of socio-economic costs and current energy use among the residential, commercial, industrial and transportation sectors.

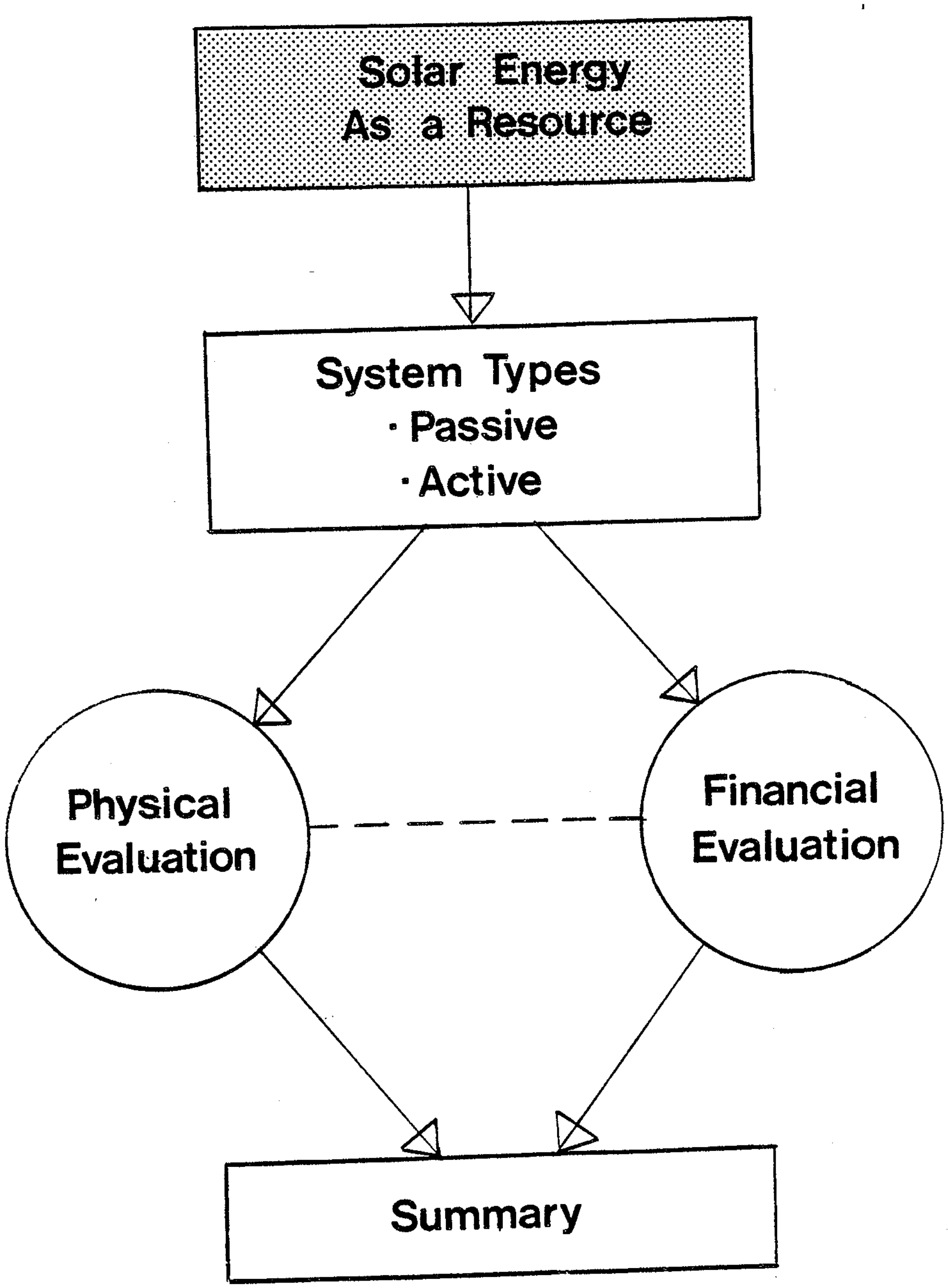
Chapter 2 presents data on the current space and water heating demand by region in Canada, and how energy is currently applied to the residential sector by different fuel types. This defines the context for the potential contribution of active and passive solar energy to meet residential energy demand. Passive solar energy systems are defined by the collection-gain and storage-recovery cycles, and in terms of the principal methods of heat transfer by radiation, conduction and convection. Generic types of passive systems are presented, defined as either "direct" or "indirect" heat gain methods. Active solar energy systems are defined in terms of their components of collector, storage, distribution and controls, and auxiliary energy supply. Generic types and operational principles of active systems are reviewed with respect to their potential impact in a residential retrofit application.

Chapter 3 identifies the perceived barriers (financial, physical and institutional) to the wider implementation of solar heating in Canada. Principle factors affecting the retrofit suitability of active and passive systems are discussed - these factors are: solar access, roof form/angle, heat storage, thermal insulation, and heating system/fuel type. Each of the passive and active system types previously identified in Chapter 2 are then evaluated with respect to each of the above retrofit criteria, in order to determine the advantages and/or disadvantages of the system types. A case study analysis of two Winnipeg areas is then carried out; the two study areas are selected by means of specific criteria so that comparisons can be made between the study areas and so that results can be extrapolated to the City of Winnipeg as a whole. Various legal mechanisms to protect solar access are reviewed with respect to their feasibility in existing urban areas. Combined with the analysis of the case study areas, this leads to specific policy recommendations to achieve the physical retrofit of solar energy systems.

Chapter 4 presents two methods used in the financial evaluation of solar energy systems: payback period and life cycle costing. Criteria or factors affecting those two methods are evaluated, such as government grants, preferred loan rates, capital costs, fuel price escalation, and property tax assessment. This leads to the identification of those financial incentives that would have the greatest impact on increasing the market share (implementation rate) of solar energy systems. In turn, policy recommendations are made and the mechanisms (ie. change in statutory law) to accomplish these recommendations are presented.

The Summary to the thesis outlines the prospects for solar energy based on case study conclusions, a mathematical model incorporating the ratio of life cycle costs of solar energy systems to conventional fuel systems, and projections for the fuel market penetration of solar energy by region in Canada. General trends for space vs. water heating applications and multiple vs. single family residential applications are identified. Several scenarios for the world energy market share of solar energy are postulated in comparison with conventional fossil fuels and nuclear power.

CHAPTER 1: SOLAR ENERGY AS A RESOURCE



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1.1 INTRODUCTION

The purpose of Chapter 1 is to outline the characteristics of solar energy as a fuel. A brief history of the application of solar energy will be given, illustrating how solar energy has been used in the past for residential space heating, crop drying, and industrial applications The use of solar energy has not become widespread due to financial, physical and institutional constraints.

Solar energy will then be defined in terms of its characteristics, ie. its thermodynamic potential, dilute intensity, and daily and seasonal variability. Different types of technologies applicable to solar energy will be introduced, with the focus in this thesis on the space and water heating of buildings. The objectives of increasing energy efficiency, contributing to energy supplies, and reducing the environmental impact of fossil fuels will be examined. Solar energy can mitigate the environmental impact and socio-economic costs associated with the use of fossil fuels by means of substitution. The argument is put foward that the future cost savings to society of the use of solar energy should take the form of financial incentives now to consumers in order to promote the wider use of solar energy. In addition, the supply life of finite fossil fuels can be lengthened by partial substitution of solar energy. The current energy use in Canada among the residential, commercial, transportation and commercial sectors is also reviewed in light of solar energy's potential contribution, in particular the space and water heating of buildings.

The summary re-iterates the main parts of Chapter 1, and concludes that the ultimate acceptability of solar energy is dependent upon the factors of economic viability, reliability, environmental impact and public attitudes towards its acceptance.

1.2 SOLAR ENERGY AS A FUEL

1.2.1 History

Dwellings using the sun's energy to be heated or cooled have been built for many years. Intuitively, early man constructed shelter to take advantage of the beneficial effects of proper building exposure to the sun and local climatic conditions. Serious studies of the sun and its potential began in the 17th century through Galileo's and Lavoisier's research.[1] Archimedes is reputed to have set fire to a Roman fleet in 212 B.C. at Syracuse using small square mirrors as hinges to focus the sun's rays on the sails of Roman boats.[2]

By the 18th century, diamonds had been melted and heat engines later operated with energy supplied by the sun. The French scientist Nicholas de Saussure constructed a solar hot box similar to present flat plate solar collectors and obtained a temperature of 88°C; and, by later chemically coating the glass surface, temperatures of 160°C were obtained.[3] In 1883, the sun was used to desalinate water in Salinas, Chile by the means of wind-pumped salt water in a 50,000 square foot still producing 5,000 gallons of water per day. Augustin Mouchot also powered a printing press in the 1880's via a sun driven steam engine.[4]

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1 Implementing Solar Technology in Canada, M.K. Burkowitz, Energy, Mines and Resources Canada, Ottawa, 1977), p. 8.

2 Ibid, p. 3.

3 "Solar Energy Through the Ages," Solplan I, R. Kadulski, (The Drawing-Room Graphic Services Ltd., Vancouver, 1977), p. 1.

4 Ibid.

However, the 19th century advances in the sophistication and application of solar energy techniques were soon to be hindered by the emergence of cheaper fossil fuels.

By 1930, the practical use of the sun's energy was made in Florida and California with domestic solar heaters; however, the market for these heaters declined in the 1940's due to competition from low-cost systems using natural gas.[5] Other countries such as Australia, Japan, Israel, and the USSR have also utilized commercial systems for the supply of domestic hot water. The first building to use space heating by means of solar hot water was constructed in 1938 at M.I.T., and an additional twenty experimental building heating projects were constructed between 1938 and 1960 in the United States.[6] The first Canadian solar heated house was built in Surrey, B.C. in 1971. Another example has been the New Alchemy Institute's "Ark" building in Prince Edward Island, a government-funded demonstration project combining the principles of passive and active solar heating and a self-sustaining, ecologically-conscious lifestyle incorporating the harvesting of food and fish in a passively solar heated greenhouse.[7]

It can be seen, then, that the use of solar energy for residential heating has a technological heritage. To date, technologies to harness and use solar energy have been adequately demonstrated, particularly for solar space and water heating. Widespread implementation of solar

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5 M.K. Berkowitz, p. 2.

6 Ibid., p. 3.

7 The "Ark" was closed in early 1981 due to a lack of government interest and funding.

energy has not occurred due to physical, financial and institutional constraints. It is clear that solar energy can have a vital role to play as a future supply source, if constraints to implementation can be overcome. Scientific advances will continue to build on the technical evolution that has occurred to date, with opportunities to make solar energy systems more cost-efficient and in turn increase their rate of use.

1.2.2 Definition

The application of solar energy to heating and cooling of buildings includes the comfort heating (and cooling to a limited extent in Canada) of residential, commercial and industrial building space, the provision of hot water, and certain technologically related agricultural applications such as greenhouse heating and crop drying. A number of different technologies exist today to convert solar energy into useful energy forms:[8]

1. Solar Heating and Cooling of Buildings (includes agricultural applications)
2. Solar Thermal Energy Conversion
3. Wind Energy Conversion
4. Bioconversion to Fuels
5. Ocean Thermal Energy Conversion
6. Photovoltaic Electric Power Systems

This thesis will focus on the first application, particularly with

8 Solar Energy: Project Independence, p. I-3.

respect to space and water heating in residential applications. There will be references made to solar photovoltaic systems in terms of land use impact and cost efficiencies.

The following definition of solar energy can be made:

> "The sun is the major source of energy for the earth. Solar energy sets the atmosphere and oceans in motion, creating the winds and ocean currents; it drives the hydrologic cycle, the primary determinant of climate; it makes possible photosynthesis - the conversion of sunlight into stored chemical energy. The sun was responsible in remote geologic time for the formation of fossil fuels. These processes constitute the conversion of the sun's energy into countless different forms before it is ultimately degraded into low-temperature heat and radiated back into space. This global system is in equilibrium with the incoming energy in the form of ultraviolet, visible and infrared radiation balanced by the outgoing heat radiation."[9]

The solar energy input to the earth is 130 watts per foot for a total solar flux of 178×10^{12} kilowatts (continuous for the whole globe) or 5.3×10^{21} BTU per year.[10] Of this annual amount, 36×10^{21} BTU per year are retained within the earth's atmosphere and surface and roughly 2.4×10^{21} BTU per year are absorbed by the surface, as illustrated by the solar energy flows in Figure 1.[11] Although solar radiation theoretically has a very high thermodynamic potential (i.e. the solar energy received by the Canadian land area greatly exceeds the present rate of energy consumption), its extremely dilute influx density and great variability have made it difficult to convert this energy

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9 Solar Energy in America's Future: A Preliminary Assessment, p. 1.

10 Solar Energy: Project Independence, (U.S. Federal Energy Administration, Washington, D.C., 1974), p. A-I-6.

11 Ibid., p. A-II-17.

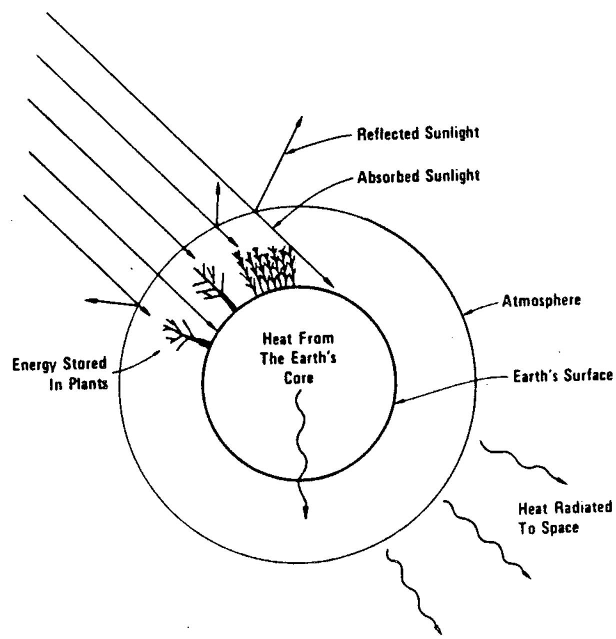
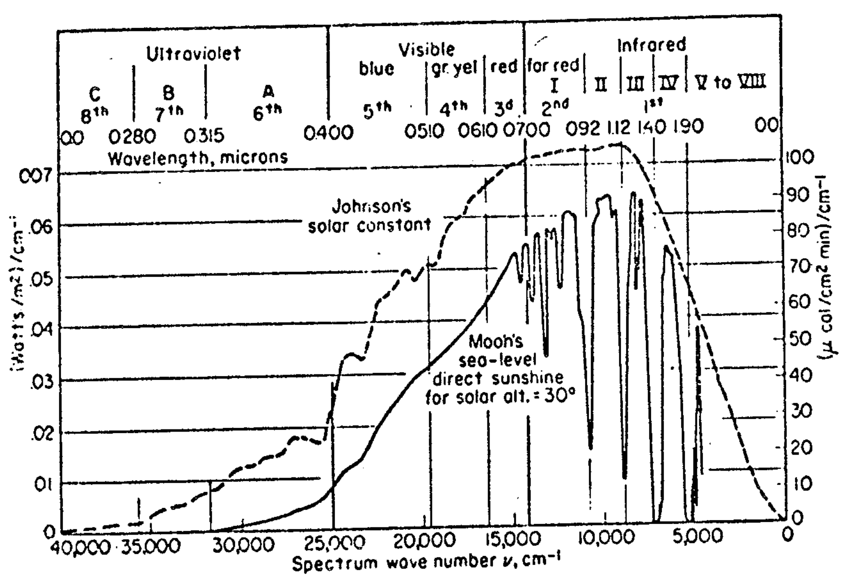


Figure 1 The Sun as the Major Source of Energy



Solar spectrum before and after atmospheric depletion.

Source: Solar Energy: Project Independence, (U.S. Federal Energy Administration, Washington, D.C., 1974), P. A-I-6.

FIGURE 1: THE SUN AS THE MAJOR SOURCE OF SOLAR ENERGY

economically with existing technology.[12]

Solar energy is intermittent with variations caused by weather and with daily and seasonal changes in the supply of sunlight and wind. As sunlight is a relatively dilute form of energy compared to fossil and nuclear fuels, large collection areas and storage units are required to generate equivalent amounts of energy, incurring higher initial costs than competing conventional fuel sources. Because solar energy is a widely dispersed energy form, unlike present concentrations of fossil fuels requiring highly developed distribution networks and centralized urban storage, it is possible to provide either small integrated systems at points of use (dispersed production), or large central power stations and associated distribution networks.[13] Dispersed systems, such as roof top residential collectors, are much less vulnerable to single point failures or damage compared to large central power systems with associated power distribution centers.

1.3 WHY SOLAR ENERGY SHOULD BE UTILIZED

1.3.1 Objectives

Energy, Mines and Resources Canada has identified two basic objectives central to Canada's future energy policy:[14]

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12 New Energy Technology, H.C. Hottel, J.B. Havard, (MIT Press, Cambridge, Mass., 1971).

13 Solar Energy: Project Independence, p. I-2.

14 Energy Conservation in Canada: Programs and Perspectives. (Energy, Mines and Resources Canada, Ottawa, 1977), p. 1.

1. "How can we increase the efficiency with which we use energy is order to reduce the rate of growth of our energy consumption in an environmentally and socially acceptable way?"

2. "How can we economically maintain and increase our energy supplies in an environmentally and socially acceptable way?"

The first objective identifies the necessity of reducing Canada's present energy requirements through the use of low-energy processes, and by altering consumption habits. Present energy demand patterns reflect the established habits of individuals, industries and governments more "appropriate to a period of cheap and abundant energy."[15] As conventional fuel supply sources, particularly non-renewable fossil fuels, become increasingly costly they will have to be used more efficiently by accomplishing a given task using fewer units of energy.

The second objective identifies the need to develop adequate supplies of energy from alternative sources in order to reduce the dependence on imported fuels, and to bridge the projected shortfall between energy supply and demand for fossil fuels, particularly oil. Thus, "the realities of the energy future indicate the wisdom of accelerated efforts to develop new and renewable energy forms, to stand beside hydro-electricity as the basis for a sustained, clean, and economically viable energy structure."[16]

The socio-economic argument for the use of solar energy in the space and water heating buildings can be based primarily on two factors: (1) the reduction of environmental impacts caused by fossil fuel use due to the partial substitution of these fuels by solar energy, as solar

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15 Ibid., p. 1.

16 The National Energy Program, (Energy, Mines and Resources Canada, Ottawa, 1980), p. 65.

energy is essentially a non-polluting "fuel"; (2) the contribution of solar energy to make up for shortfalls in fossil fuel supply, thus lowering Canada's dependence on imported fuels (particularly oil) and by means of substitution, lengthening the stock life of the finite fossil fuels.

1.3.2 Environmental Impact

One major advantage of the use of solar energy is that it is essentially non-polluting when compared to conventional fuels used in the residential sector, particularly oil and gas. Environmental groups have promoted solar energy for this reason, but solar energy has been seen by governmental agencies as an energy supply source to help match energy demand with supply. When applied to the heating and cooling of buildings, solar energy does not introduce any new materials requirements (other than collector components) and reduces pollution to the degree that it replaces conventional energy sources.

Figure 2 "Environmental Impact of Conventional Energy Technologies," illustrates the by-products from the use of fossil fuels, nuclear electric power, and hydroelectric power, and their wide-ranging effects on the ecology (air, water, and land) and human health and safety. While hydro-electric power is a non-polluting energy source, it can have negative effects on water levels, land, and marine ecological systems. Combustion of fossil fuels results in the release of particulates, sulfur oxides, carbon oxides, nitrogen oxides, and hydro-carbons from residential use, generating stations, and refinery or fuel processing plants.

Environmental Impact of Conventional Energy Technologies

	Energy Source		
Impact on	Combustion of Fossil Fuels	Hydroelectric	Nuclear Electric
Air[a]	Release of: Particulates - A,B,C Sulfur oxides - A,B,C Carbon oxides - A,B,C Nitrogen oxides - A,B,C Hydrocarbons (by evaporation and incomplete combustion) - A,B, C	Nil	Release of: Tritium[b] - B Iodine-131[b] - B Particulates[b] - B Noble gases[b] - B (Krypton-85 Xeron-133) Radon[b] - D Radium dust[b] - D Sulfur dioxide - E
Water[a]	Waste heat - B Acid (dissolved - A,B SO_2 and CO_2)	Nil	Waste heat - B Acid (dissolved - E,D) Tritium[b] - B Gross β,γ[b] - B Radium-226[b] - D,C Arsenic - C Nitrates - C Sulfates - D Ammonium - C
Land	Strip mining for coal Fly ash and bottom ash disposal	Altering water levels Disturbance of natural flow patterns Flooding of dry areas Drainage of wet areas Eco-system disturbance (fish, flora, fauna)	Solid waste disposal in trenches[b] Tailings from mines buried in shallow landfill sites Tentative: burial of high level waste in containers Plutonium production[b]
Human Health	Black lung disease - coal Lung irritants from air pollutants	Nil	Increased cancer and leukemia risk from radiation Increased genetic mutation and birth defects from radiation
Human Safety	Explosions - gas,oil Fires - gas,oil Transportation spills - oil accidents - coal,oil	Flooding	Reactor accident - radiation exposure Transportation - radioactive materials spill Sabotage and terrorism Human fallibility

a Release originating from
A - homes
B - generating stations
C - refinery or fuel processing plants
D - resource extraction site
E - secondary industry - here, heavy water plants

Source: Implementing Solar Technology in Canada, M.K. Berkowitz, (Energy, Mines and Resources Canada, Ottawa, 1977), P. 107.

FIGURE 2: ENVIRONMENTAL IMPACT OF CONVENTIONAL ENERGY TECHNOLOGIES

In a study done by M.K. Berkowitz of Energy, Mines and Resources Canada, costs can be attributed to air pollutants from residential combustion in terms of health and ecological effects. By distributing the specific costs among the conventional residential fuels, costs of air and thermal pollution per single-family dwelling unit can be derived. In Table 1, the 1990 scenario projects a different distribution of energy supply for the residential sector, due to a reduction in the use of oil and an increase in the use of utility coal for space heating and electric power generation.

Table 1: Air and Thermal Pollution Costs Per Single Family Dwelling Unit (Canada)[17]

Source ($1980)	1975 Scenario	1990 Scenario
Home Oil	$ 3.136	$ 2.242
Home Natural Gas	.222	.197
Utility Oil	.119	.168
Utility Natural Gas	.026	.046
Utility Coal	6.765	18.064
Thermal	.484	1.316
	$ 10.750	$ 22.030

The present value in 1980 dollars of pollution costs saved through the substitution of solar energy can be projected over a 25 year period to 2005 for single and multiple dwelling units, assuming implementation rates of 5.0 or 10.0% for new dwellings and an annual retrofit rate of .23% for existing dwelling units in Canada.[18] The pollution savings

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17 Implementing Solar Technology in Canada, M.K. Berkowitz, (Energy, Mines and Resources Canada, Ottawa, 1977), p. 90.

18 "Retrofit" is the adaptation of an energy technology, ie. a solar energy system, to an existing dwelling vs. a built-in system incorporated in a new dwelling design. An annual "retrofit rate" of .23% indicates that on the average .23% of existing dwellings would retrofit a solar energy system every year, or about 1 in every 435 dwellings.

generated in Table 2 could be even greater if a larger retrofit rate was assumed, and conventional fuel and pollution savings for the existing housing market could greatly outweigh savings generated in the new housing market.

Table 2: Present Value ($000) of Pollution Savings Over 25 Year Horizon[19]

Implementation Rates:	1975 Scenario*		1990 Scenario*	
Dwelling Unit	5.0%	10%	5.0%	10%
Single	26,238	32,420	53,765	66,432
Multiple	19,340	26,098	39,640	33,492
TOTAL:	45,578	58,518	83,405	119,924

* Assumes an annual retrofit rate of .23% for existing dwelling units.

It can be argued that these pollution savings are savings attributable to governments in terms of the reduction of negative externalities. National and/or provincial governments can then redistribute these future savings (over the 25 year horizon) to residential energy consumers, but more heavily weighted in the early years in order to provide incentives for consumers to adopt solar energy.[20]

Another environmental impact resulting from the burning of fossil fuels, not taken into account in Figure 2, is the effect on the world's heat balance. Even though fluctuations in the Earth's average temperature have declined slightly since 1940, "heat island effects over major cities have already created significant changes in climate by waste heat

19 Source: M.K. Berkowitz, p. 105.

20 Other government savings can be attributed to the reduction in subsidies for imported fossil fuels due to the reduction in demand through fuel substitution by solar energy.

rejection at the generating sites and the end use parts."[21] A major shift in the use of solar energy by the year 2000 could reduce or negate these atmospheric "greenhouse" effects through a reduction in waste heat rejection at the generating site. The continued use of fossil fuels into the middle of the 21st century could further raise the concentration of carbon dioxide (CO_2) in the atmosphere, possibly resulting in an increase in global atmospheric temperature - dependent on the degree of control of particulate emissions.[22]

The widespread implementation of solar energy is not without some attendant environmental impacts. It has been speculated that local or meso-scale climate changes might occur due to large collector surfaces, particularly large-scale electric-generating plants.[23] In addition, large central solar power plants providing district space heating or generating electricity have land use impacts, due to the large land areas required to collect sufficient energy for a centralized plant with a distribution network. Figure 3, "Land Requirements for Electricity Production" compares the land areas required for solar photovoltaic and solar thermal power plants versus power plants using coal or biomass. However, dispersed solar collection units, i.e. roof-mounted collectors, usually permit dual use of land area while not requiring expensive urban land (in the case of urban utility systems).

Large-scale applications of solar energy will hae to be examined

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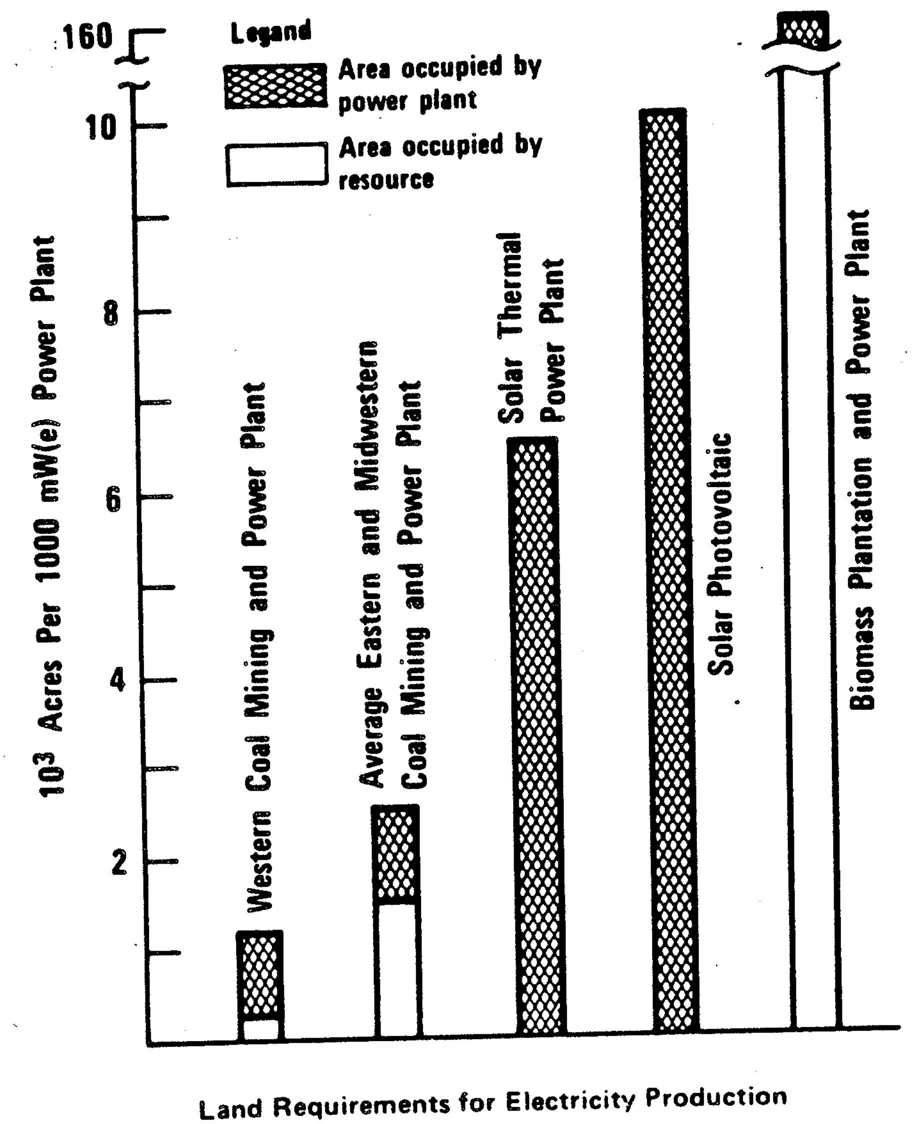
21 Solar Energy: Project Independence, p. I-28.

22 Ibid., P. A-II-iii.

23 Ibid., P. A-II-iv.



Source: Solar Energy in America's Future: A Preliminary Assessment, (U.S. Energy Research & Development Administration, Washington, D.C., March 1977), P. 53.

FIGURE 3: LAND REQUIREMENTS FOR ELECTRICITY PRODUCTION

to ensure that they are at least as environmentally benign than the conventional systems they replace.

1.3.3 Energy Demand and Supply

A second major argument made for the increased use of solar energy is the savings to society of the non-renewable resources which would otherwise be used for space and water heating. The substantial reduction in the consumption of fossil fuels would allow the use of those fuels for processes for which alternative energy sources are either not yet practical or cost-effective, such as transportation and industrial processes. This in turn would lengthen the supply life of the finite fossil fuels, allowing additional time to develop alternative energy fuels for these sectors.

World fossil energy resources could be essentially exhausted within the next century if past growth rates of consumption continue; coal will last for centuries only if the rate of consumption does not grow. In addition, it is problematic to expect nuclear sources to replace fossil fuels completely because of unresolved technical problems and uncertain acceptability to the public.[24]

Figure 4, "Canadian Energy Flows (1973)," illustrates the sources of energy (hydro, nuclear, natural gas, coal, and petroleum) and how they are distributed among the principal end-use sectors of housing, commerce, industry, and transportation. The residential sector current-

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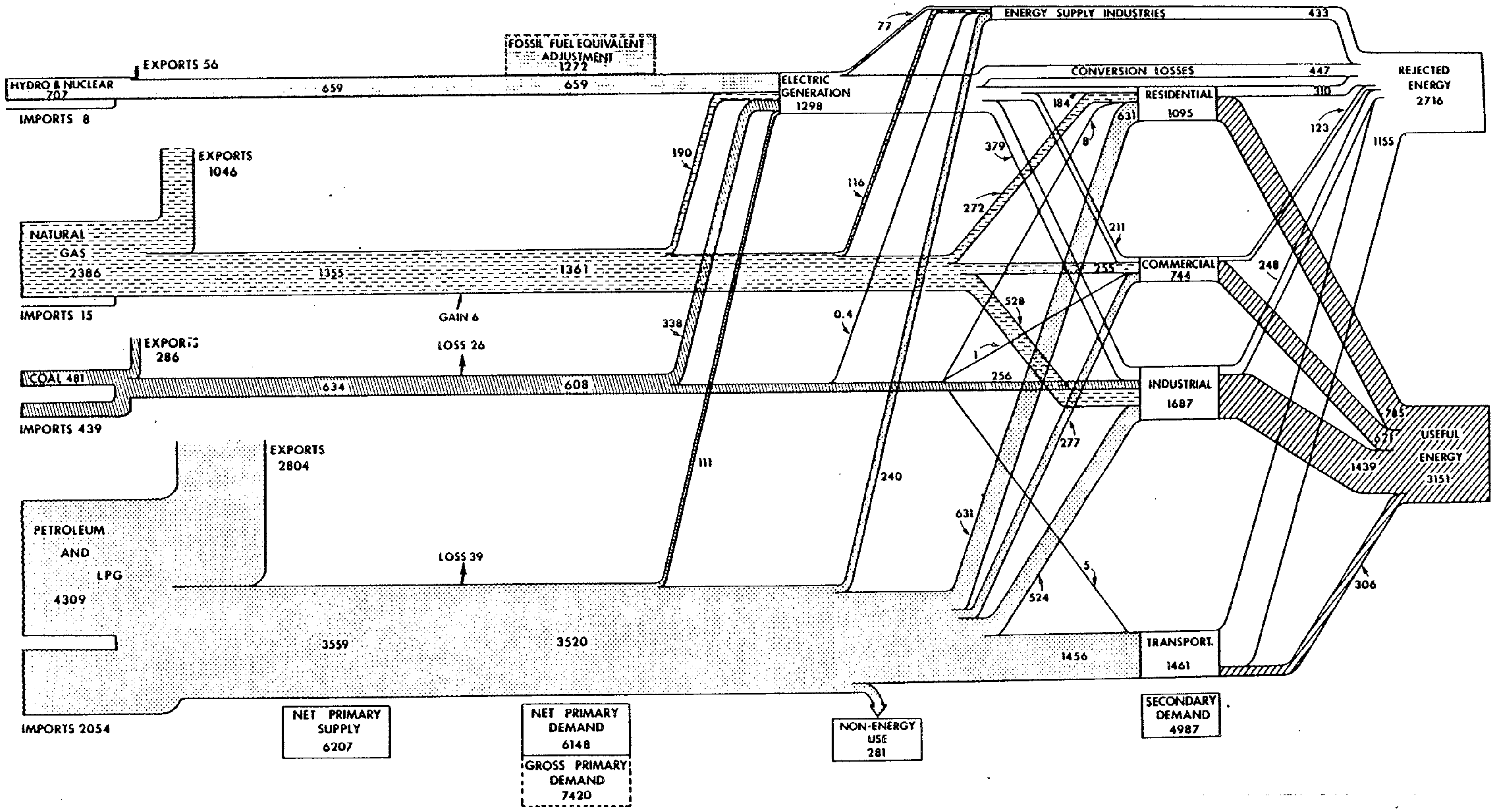
24 Solar Energy in America's Future: A Preliminary Assessment, p. 72.

CANADIAN ENERGY FLOWS, 1973
(trillions of BTU's)



Source: Energy Demand Projections: A Total Energy Approach, (Energy, Mines and Resources Canada, Ottawa, 1977), P. 19.

FIGURE 4: CANADIAN ENERGY FLOWS: 1973

ly accounts for approximately 20% of secondary energy consumption in Canada, although this proportion has been declining.[25] Space and water heating of buildings (including non-residential applications) constitutes about 32% of total secondary energy consumption, so the widespread implementation of solar energy has considerable potential for reducing non-renewable fuel demand in Canada.[26]

Figure 5, "Distribution of Net Primary Energy Demand," diagrams the demand distribution among the primary end use sectors including the energy supply sector. The 1990 Conservation Scenario illustrates the change in distribution among these end-use sectors due to conservation measures, i.e. the residential sector is projected to decline from 19% of net primary energy demand in 1972 to 13% in 1990.

In the residential sector, the most immediate problem will be the use of fuel oil for space and water heating. Fuel oil currently accounts for 53.0% of residential space heating in Canada, and has a market presence for residential water heating in the Maritimes and Quebec.[27] World supplies of conventional fuel oil are projected to decline after

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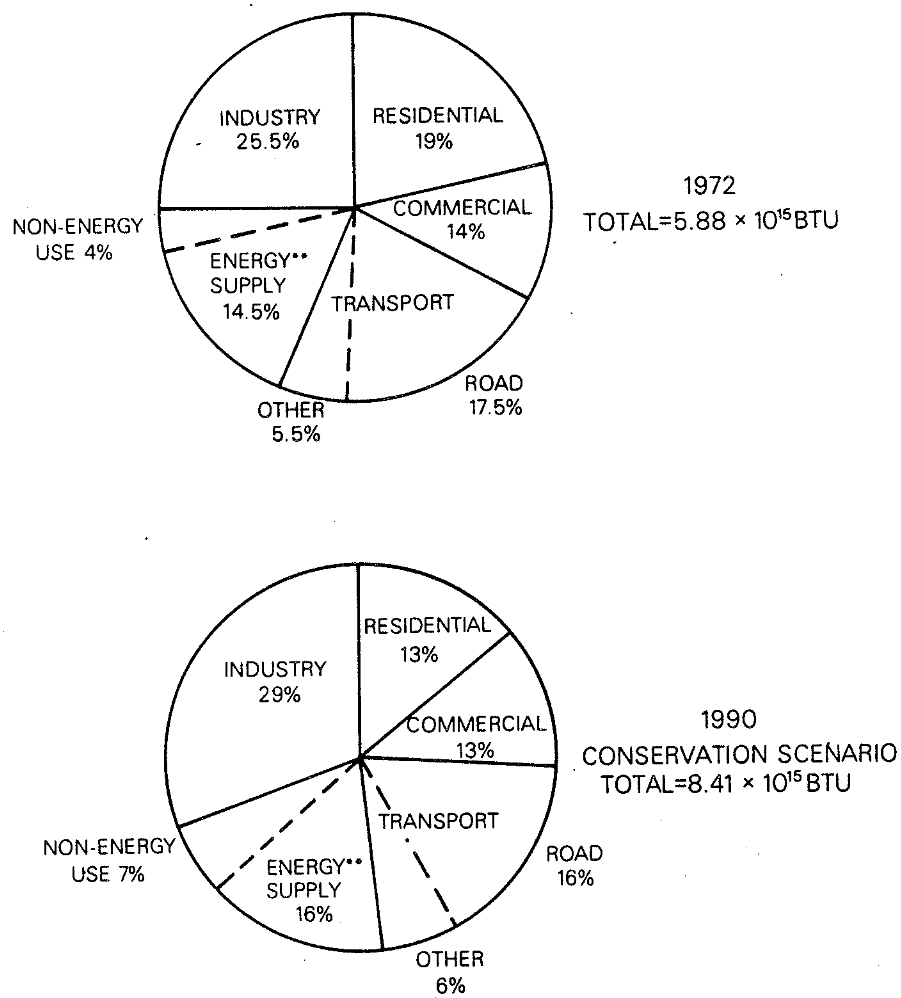
25 Energy Conservation in Canada: Programs and Perspectives, p. 16. "Secondary" energy consumption is defined as net primary demand less conversion losses and non-energy uses (see Figure 4). "End-use" sector is a sector of the economy (ie. residential, industrial, commercial) that generates the demand for specific fuels.

26 Solar Energy for Existing Homes, R. Kadulski, T. Lyster, (The Drawing-Room Graphic Services Ltd., Vancouver, 1978), p. 1.

27 M.K. Berkowitz, p. 84. Fuel oil has 42% and 23%, respectively, of the market shares for single-family residential water heating in the Maritimes and Quebec. West of Quebec oil has no modest share of single-family water heating, but does contribute 10% and 24%, respectively, of multiple-family water heating in Ontario and B.C. Source: Statistics Canada, Household Facilities Equipment, 64-202.

Distribution of Net* Primary Energy Demand, 1972 and 1990



*Excludes adjustment to convert hydro and nuclear electricity to approximate fossil fuel equivalent.

**Includes conversion losses.

Source: Energy Conservation in Canada: Programs and Perspectives, (Energy, Mines and Resources Canada, Ottawa, 1977), P. II.

FIGURE 5: DISTRIBUTION OF NET PRIMARY ENERGY DEMAND: 1972 & 1990

1990, and thus the substitutional use of solar energy, particularly for the residential market currently using oil, could help to lengthen supplies of less expensive conventional oil.

Consumer decision to replace oil with solar energy (other than a back-up supply system) will, of course, be dependent upon the competing costs of natural gas or electricity and any added government financial incentives to promote the use of solar energy. However, it can be reasoned that solar energy should be accounted for in terms of primary fuel saved from the marginal resource - the least efficient, most costly new source for which solar energy substitutes - rather than the average or "blended" price of current oil supplies from conventional, non-conventional, and imported sources.

Solar energy policy, therefore, should be viewed in terms of what the technology can contribute towards national self-sufficiency in energy and security of supply.

1.4 SUMMARY

Solar energy is an inexhaustible and essentially pollution-free energy resource that can be collected and used to heat and cool buildings. The contribution in Canada of solar heating, and to a limited extent solar cooling, will be to reduce the demand imposed on conventional fuel supplies in residential, commercial, and industrial space and water heating applications. In addition, external diseconomies, such as health costs due to air pollution from the combustion of conventional fuels, should influence public decision-making to provide finantional fuels, should influence public decision-making to provide financial incentives to promote the use of solar energy.

To summarize, the rate of implementation and the public acceptability of solar energy will be dependent upon a number of factors:

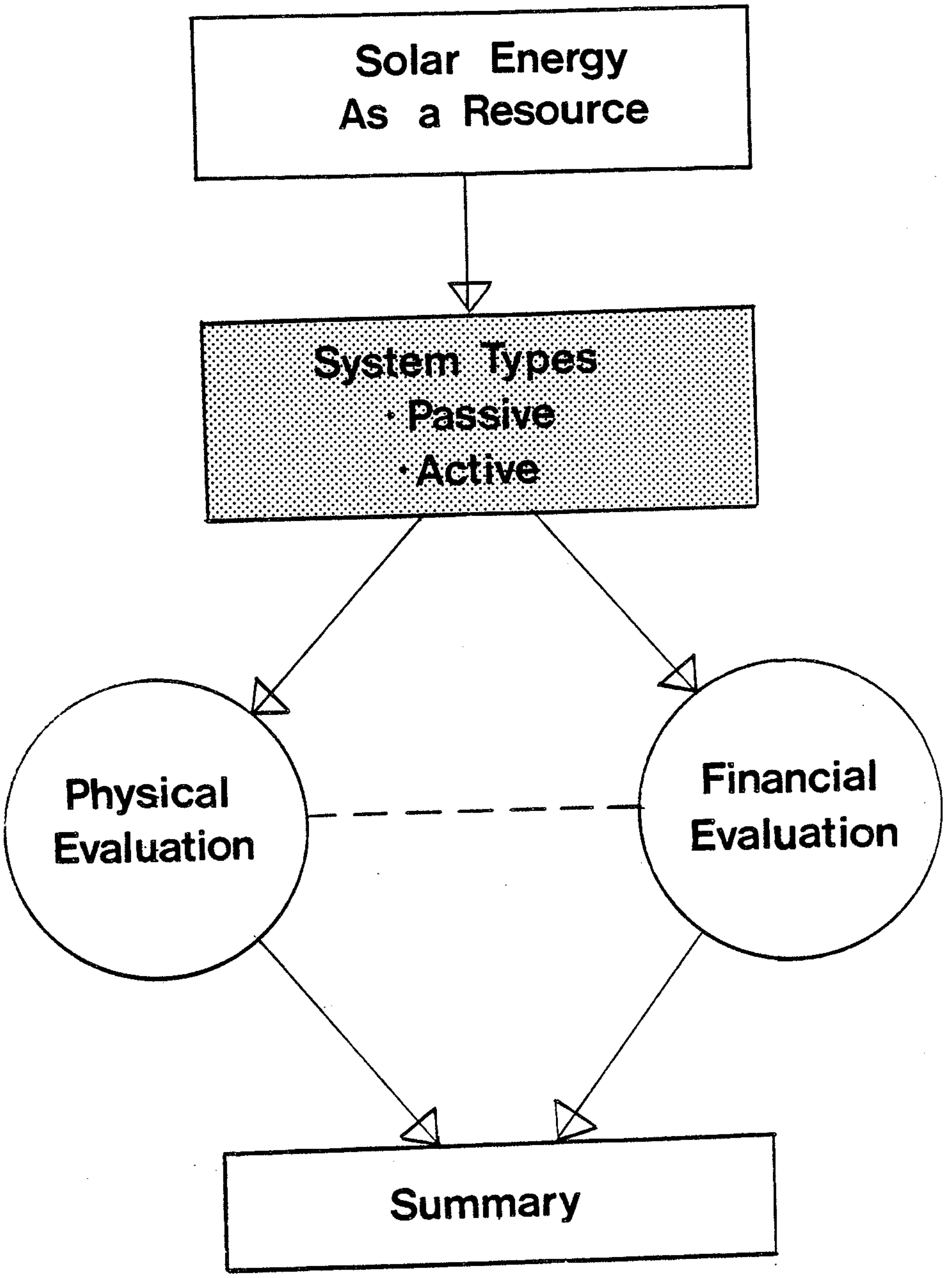
1) The reduction in the environmental impact of conventional fuels due the partial substitution of solar energy and the resultant decrease in pollution attributable to fossil fuels.

2) The savings to society (both government and consumers) of the non-renewable resources which would otherwise be used for space and water heating, in terms of the additional costs over solar energy for the amount of fuel substituted.

3) The contribution of solar energy in meeting overall energy demand (i.e. supply shortfalls) and in lengthening the supply life of conventional fuels due to partial substitution.

The ultimate acceptability of solar heating, cooling, and generation of electricity will depend on their economic viability, reliability, environmental impact and public attitudes towards their acceptance.

CHAPTER 2: SOLAR ENERGY SYSTEMS FOR RESIDENTIAL USE



STRUCTURE

2.1 INTRODUCTION

The purpose of Chapter 2 is to outline how residential energy is used in Canada in terms of demand and supply, and to define and evaluate the generic types and operational principles of solar energy systems applicable to residential energy use.

Space and water heating currently comprise 88% of residential energy use; however, annual space heating loads vary by region while annual water heating loads have little regional variation in Canada. In terms of residential energy supply, the home heating market share is presented by fuel type (fuel oil, natural gas, electricity) for Canada and by regional distribution. Solar energy system types can then be evaluated in terms of their potential contribution to residential energy use, keeping in mind the regional variations of space and water heating, and current fuel supply distribution in Canada.

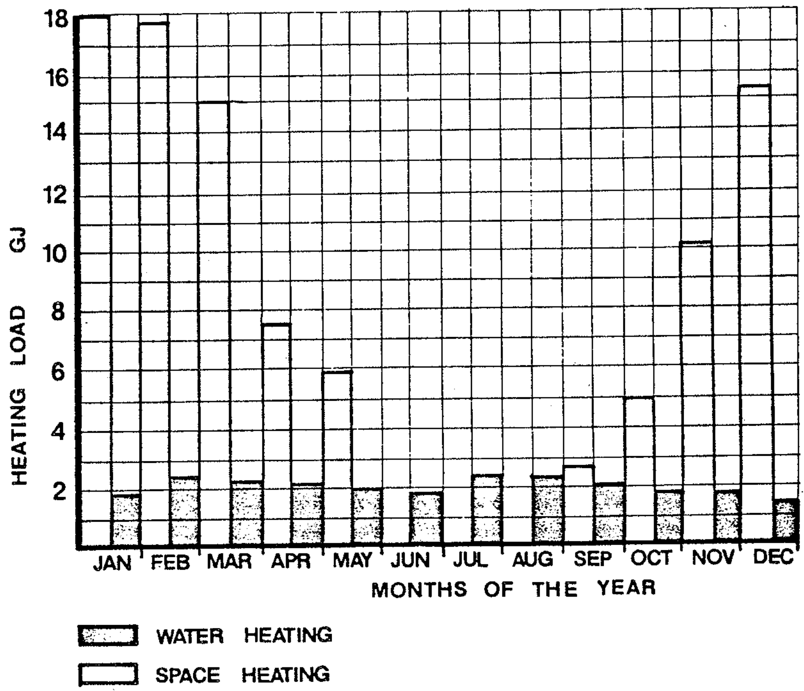
Solar energy systems take the form of either "natural" (passive) or "engineered" (active) system types. Passive solar energy systems have the objective of maximizing winter solar heat gain and minimizing summer solar heat gain to residential living space. The principles of heat collection (gain), heat storage, and distribution (heat recovery) by means of radiation, conduction or convection, are outlined in Section 2.4.1. Passive solar systems are then classified as either "direct" or "indirect" gain, and individual types of direct (window wall, attached sunspace) and indirect (mass wall, mass roof, isolated gain thermosiphon) systems are reviewed. Section 2.5 "Active Solar Energy Systems" defines active systems in terms of their main components: collector, storage unit, distribution and controls, and auxilliary energy supply. Generic types and operational principles are then reviewed, based on an air vs. fluid thermal transfer medium (flat plate liquid, evacuated tube, flat plate air). The components of back-up heating systems, short term vs. long term heat storage, and storage mediums (rocks, eutectic salts, water) are evaluated in terms of their positive and/or negative impacts on retro-fitting a house with an active solar energy system.

The summary re-iterates the main points of Chapter 2, and concludes that the thermal upgrading of an existing house prior to the retrofit installation of a passive or active system will increase the operating efficiency of a solar energy system, and lessen the impact upon an existing house in terms of collector area, and storage volumes required.

2.2 RESIDENTIAL ENERGY DEMAND

It should be noted that, within the residential sector in Canada space heating and water heating accounted for about 88% of all energy demands in 1972. These two applications, then, provide the focus for this chapter due to their suitability for utilizing low grade heat from passive collection means or from flat plate solar collectors.

Figure 6, "Secondary Energy Consumption in Residences: 1962-72", indicates the respective shares for space heating and water heating of total residential energy demand in Canada. Space heating loads in single family and multiple family dwellings vary on a regional basis in the following manner:



Space and water heating load for well insulated bungalow, 138 m². in Toronto.

Secondary Energy Consumption in Residences, 1962-1972
(10^{12} Btu)

	Total Residential			Space Heating[a]		Water Heating[a]	
Year	*Consumption*	*Per cent of Total Secondary Consumption*	*Per cent Average Annual Growth Rate from 1962*	*Consumption*	*Per cent of Total Secondary Consumption*	*Consumption*	*Per cent of Total Secondary Consumption*
1962	762.9	24.0	–	534.1	16.8	137.3	4.3
1965	866.2	22.5	4.3	600.3	15.8	155.9	4.1
1970	1,036.2	20.5	3.9	725.3	14.4	186.5	3.7
1972	1,131.6	20.6	4.0	792.1	14.4	203.7	3.7

SOURCE: Statistics Canada, *Detailed Energy Supply and Demand in Canada*, 1958-1969, 1970 and 1972. Catalogue 57-505.

[a]Space heating and water heating are assumed to comprise 70 per cent and 18 per cent respectively of total residential energy consumption. This represents most of the energy used as heat in this sector and all of it is consumed at "low" temperatures, i.e. temperatures below 100°C. See V.R. Puttagunta, *Temperature Distribution of The Energy Consumed as Heat in Canada*, Atomic Energy of Canada Ltd., Pub. No. AECL-5235, Oct. 1975.

Source: "Solar Energy Technology," Energy Conservation Handbook, (Royal Architectural Institute of Canada, Ottawa, 1979).

FIGURE 6: SECONDARY ENERGY CONSUMPTION IN RESIDENCES: 1962 - 1972

Table 3: Annual Space Heating Load by Region (1972)[1]

Dwelling Type	Atl.	Que.	Ont.	Pra.	B.C.
	Annual Space Heating Load (10^6 KJ/Unit)				
Single	64.7	63.4	56.6	84.2	40.5
Multiple	45.0	44.1	39.3	58.9	27.9

Source: Solar Heating and the Oil, Gas & Electricity Industries, p. 11.

It can be seen that the Prairie region has the highest space heating load for single and multiple-family dwellings, while B.C. has the lowest space heating load.

The annual water heating load, however, varies little on a regional basis as it is a function of similar demands across Canada. The annual water heating load for single family dwelling units is 15.9 x 10^6 kilo-joules (KJ) per unit, and 12.7 KJ/unit for multiple family dwelling units. Figure 7 depicts the average daily demand pattern for water heating in single family dwellings, which varies little over the year or by region. The daily demand for space heating will, however, vary on a seasonal and a regional basis and thus must be case specific.

When examining generic types of passive and active solar energy systems and their applicability to space and water heating, it should be noted that water heating accounts for about 18% of average Canadian residential energy use, and space heating accounts for about 70% of

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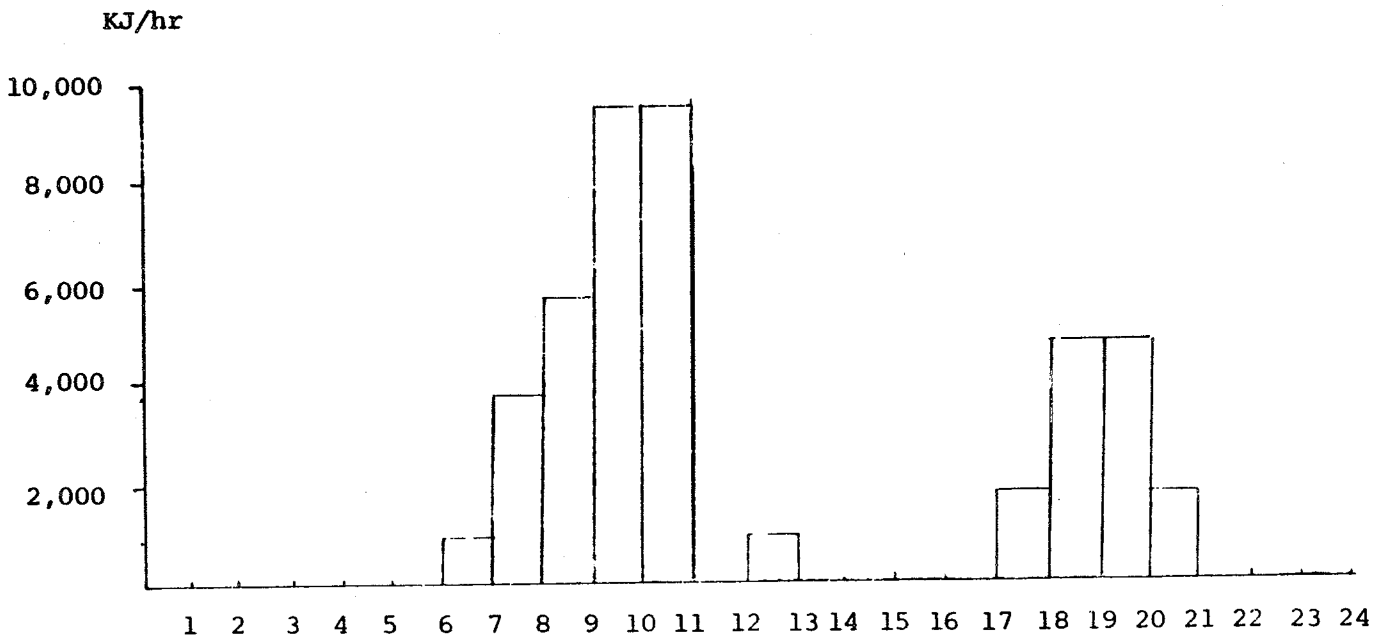
1 These heat loads are representative of well insulated buildings with levels of heat loss that can be achieved in new construction. Existing housing stock will have higher annual space heating loads dependent upon age, type of construction, and levels of insulation. The multiple family units have losses equivalent to about 70% of the single family unit heat losses.

Water Heating Requirements

Domestic water energy requirements are assumed to be 15.9 x 10^6 KJ and 12.7 x 10^6 KJ for single and multiple family units respectively. This energy demand is assumed to be spread equally throughout the year with a constant characteristic demand pattern over the 24 hours of the day, corresponding to the time of use for the water as shown

DAILY DEMAND FOR WATER HEATING IN SINGLE FAMILY DWELLINGS



Source: Solar Heating and the Oil, Gas and Electricity Industries, (Energy, Mines and Resources Canada, Ottawa, 1979).

FIGURE 7: DAILY DEMAND PATTERN FOR WATER HEATING

residential energy use.[2] Thus it should be noted that a domestic solar water heating system, while potentially cost-efficient, will provide only 20% of the residential energy budget. It is in the area of space heating systems that the greatest contribution to energy supply can be made by passive and active solar collection.

2.3 RESIDENTIAL ENERGY SUPPLY

Home heating in Canada is currently provided by fuel oil, natural gas, and electricity; electricity, in turn, is generated by hydro, nuclear and fossil fuels. Table 4, "Home Heating Market Share: 1975", indicates the supply distribution of these fuels to the residential heating sector.

Table 4: Home Heating Market Share: 1975

Residential Heating Fuel				Final Market Share (%)
Fuel Oil:	53.0%			53.00
Natural Gas:	36.0%			36.00
Electricity:	11.0%*			
* Generated by:		Hydro	62.0%	6.82
		Nuclear	4.0%	.44
		Fossil Fuel**	34.0%	
** Fossil Fuels Used:		Oil	18.0%	.67
		Natural Gas	14.0%	.52
		Coal	68.0%	2.54
				100.00

Source: Implementing Solar Technology in Canada, M.K. Berkowitz, 1979, p. 84.

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2 Figures derived from Figure 6. Total includes residential electricity use.

It is also interesting to note the regional market shares of conventional fuels for domestic water heating for existing Canadian housing stock, both for single-family and multiple-family use (Table 5).

Table 5: % Market Shares of Fuels for Domestic Water Heating

	Single Family			Multiple Family		
Region	Oil	Gas	Elect.	Oil	Gas	Elect.
Atlantic	42	0	58	60	0	40
Quebec	23	0	77	20	10	70
Ontario	0	42	58	10	50	40
Prairies	0	76	24	0	83	17
B.C.	0	43	57	24	48	28

Source: Solar Heating and the Oil, Gas and Electricity Industries, Energy, Mines and Resources Canada, 1979, p.24.

Apart from hydro-electric power and to a small degree wood, Canadians are completely dependent on non-renewable sources of energy.

2.4 PASSIVE SOLAR ENERGY SYSTEMS

Solar energy is a unique form of energy because it appears in so many forms, producing fuel, power, electricity and heat. Forms of renewable solar energy include wind power, biomass, and hydraulic power. Of these forms of solar energy, energy capture can be achieved by two general types of collectors: natural and engineered. Passive solar energy can be naturally collected through geophysical processes such as warming solids or liquids in storage form, and then utilized when heat is re-emitted and distributed from storage through the natural processes of radiation, conduction and convection. Solar energy can also be captured by engineered solar collectors explicitly designed to distribute heat for space and water heating (flat plate or focussed collectors), or to generate electricity by means of solar-activated photovol- taic cells.

2.4.1 Definition and Classification

There is significant potential for the passive use of solar energy through the correct utilization of the design and alignment of buildings. Passive systems incorporate a series of architectural principles that maximize solar heat gain during the winter and minimize the solar heat gain during the summer.[3] With a passive system, the building itself is designed to collect, store and distribute the solar energy, while an active system has separate components and mechanical means for collection, storage and distribution. In a passive system, the functions of solar energy collection and storage are generally combined in a single unit that is located in or adjacent to the living space, and the transfer of heat (direct or stored) takes place by radiation or natural convection. This "unit" might be a specially designed energy storage wall that absorbs heat, an attached greenhouse or "sunspace", or it might be the house structure itself.

The essential design intent of a passive solar heating system is "to make the building itself, rather than its mechanical subsystem, a modulating heat valve accepting, retaining or rejecting solar radiation as required by the building in juxtaposition with its local climate.[4]

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3 Solar Energy in America's Future: A Preliminary Assessment, (U.S. Energy Research and Development Administration, Washington, March 1977), p. 18.

4 Passive Solar Heating in Canada: A Discussion Paper, Bruce D. Gough, (Energy, Mines and Resources Canada, Ottawa, 1980), p. 27.

Solar gain is received through windows and/or absorbed through walls, and storage is absorbed by means of "mass" walls that retard heat transmission (time-lag effect) and re-emit heat later resulting in a flattening of the temperature variation curve inside the building. Consequently, there is a net reduction in the total heating requirements of the building, in turn minimizing the backup heating system load. Heat distribution is accomplished by natural means of radiation, conduction and convection, but can be actively assisted to improve convection to living spaces away from the passive collection "unit" and to prevent overheating in the space adjacent to the collection unit. Thus, the design of a passive solar heating system must achieve an optimal balance between storage of solar heat gains and the control of natural heat transfer from storage materials in order to maintain acceptable comfort conditions within the living space.

Some solar heated houses are combinations of both active and passive design concepts, because they can gain heat directly through windows and walls even when various mechanical devices are used to collect, store and distribute solar heat to the living space.[5] Passive systems utilizing active distribution either from the collection or storage areas, but not both, are termed "hybrid" systems as they exhibit both active and passive characteristics. Table 6 illustrates the matrix of active, passive and hybrid systems as determined by the operational mode of their collection-gain and storage-recovery cycles.

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5 "Passive Solar Heating Systems," Hannah Pavlik, (Colorado State University Extension Service), Fort Collins, Colorado, July 1979, p. 1.

Table 6: Matrix of Solar Energy System Types

		Storage-Recovery Cycle: Forced	Storage-Recovery Cycle: Natural
Collection-Gain Cycle	Forced	"pure" ACTIVE	hybrid (PASSIVE)
	Natural	hybrid (ACTIVE)	"pure" PASSIVE

Source: Passive Solar Heating in Canada: A Discussion Paper, Bruce D. Gough, (Energy, Mines and Resources Canada, Ottawa, 1980).

For purposes of definition, this section on passive systems will include "hybrid" systems with forced collection-gain cycles and natural storage-recovery cycles, e.g. fan-assisted heat gain systems to improve heat distribution by convection. Hybrid systems including forced storage-recovery cycles are included under "active" systems.

2.4.2 Generic Types and Operational Principles

There are essentially two means of utilizing passive solar energy:

1) Direct,

2) Indirect.

Direct passive systems allow solar radiation to enter directly into a building sunspace through transparent surfaces, where it can be distributed by means of internal air convection currents or absorbed as sensible heat in floor and wall masses and later re-radiated into the building's interior. "Direct" systems include direct window gain systems integral to the building's structure, or attached greenhouses or sunspaces. Buildings made from materials with high heat-holding capacity and with a relatively large ratio of storage area to glass area are characteristic of direct gain passive structures.[6]

Indirect passive systems absorb solar radiation external to the heated space, after which heat is "indirectly" transmitted to the building space by natural conduction or convection. Indirect systems include mass wall storage, such as the Trombe wall or the water tube wall, mass roof storage, and isolated gain systems such as the thermosiphon system utilizing the fluid convective loop principle. Indirect systems such as the water tube wall can be hybrids or combinations of both "direct" and "indirect" systems. This occurs when solar collection and storage (water columns or drums) are both contained within the living space, and not external to it.

Each of these passive system types will be examined as to their principles of operation, design considerations, and factors influencing their utilization. Figure 8 illustrates the generic classification of these passive solar heating systems, which will be explained in the following sections.

1) Direct Gain Systems:

(i) Window and Storage Systems:

The simplest type of passive solar house is one with a large expanse of double-paned windows facing south, permitting direct radiative gain to the living space. Thermal storage is achieved by means of

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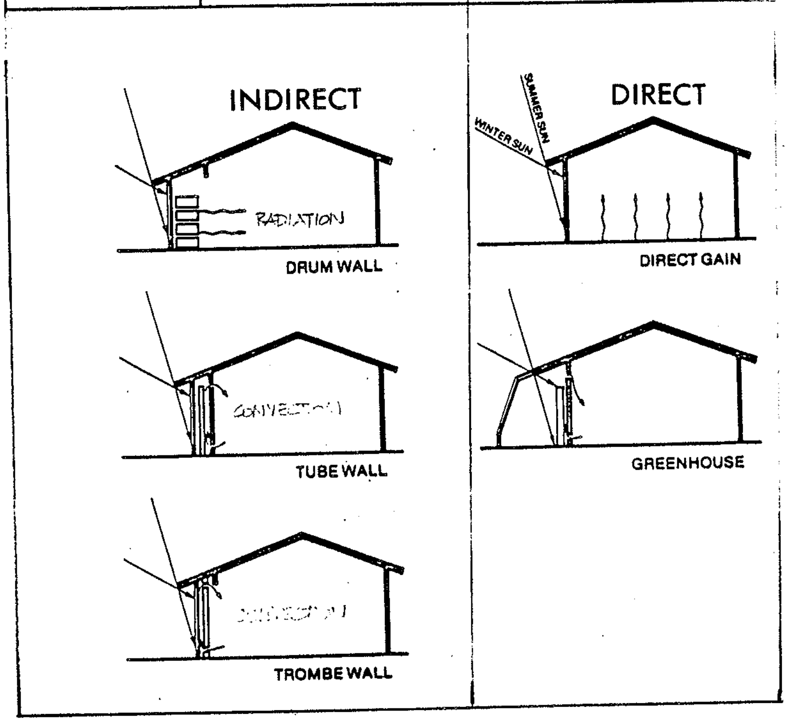
6 Hannah Pavlik, p. 1.

	PASSIVE SOLAR HEATING			
	INDIRECT		DIRECT	
	THERMOSIPHON	MASS	SUNSPACE	WINDOW
Collection: Space	Remote	Remote	Attached	Integral
Storage: Space	Coupled	Coupled	Coupled	Isothermal
Prime Thermal Mode	Convective	Conductive	Radiative	Radiative
Thermal Sequencing	Sun ↓ Collection ↓ Storage ↓ Space	Sun ↓ Collection Storage ↓ Space	Sun ↓ Space Collection Storage ↓ Space	Sun ↓ Space Collection Storage



Sources: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley, California, 1980), P. 13.

Passive Solar Heating in Canada: A Discussion Paper, Bruce D. Gough, (Energy, Mines and Resources Canada, Ottawa, 1980), P. 29.

FIGURE 8: GENERIC CLASSIFICATION OF PASSIVE SOLAR HEATING SYSTEMS

high thermal capacity walls and floors that have solar exposure, using water and/or high mass solids as the storage medium. Daytime overheating of the living space can be minimized if there is a relatively large storage mass to window collection area ratio, suitable shading of the collection surface by overhangs, and adequate external ventilation to prevent overheating during the summer. Insulating shades or screens are also required to minimize heat loss at night; double or triple-glazing of the window collection area also reduces night-time heat loss.

Passive solar heat gains through windows are intrinsic with the construction of any building, and already contribute 12.5% of the gross annual residential heating energy requirement of the existing residential building stock, or 2.26% of the total annual energy consumption in Canada.[7] On an annual basis, clear, vertical south-facing double and triple glazing transmit more usable energy than the amount lost by conduction at all major locations in Canada.[8] With careful design and conservation measures as outlined above, this passive solar system type can contribute between 30 to 50% of the annual residential heating requirements.[9] In an existing wood frame construction house with gypsum wallboard, the south-facing window area should be limited to about 6% of the floor area (for the Canadian Prairie climate). If extra mass storage is added to the walls and floors, and overall insulation levels are upgraded, then the window collection area should exceed 6% of the floor area.

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7 Bruce D. Gough, p. 2.

8 Ibid., p. 3.

9 Energy Efficient Housing - A Prairie Approach, (University of Saskatchewan Dept. of Mechanical Engineering, Energy Research Development Group, January 1981), p. 21.

(ii) Attached Sunspace or Greenhouse:

Greenhouses or sunspaces can be added to existing houses (or incorporated into new house designs) on south-facing walls, trapping radiated solar heat and using the existing south common wall for heat storage. Thermal storage can also be accomplished by means of masonry floors, water containers or rock beds. Greenhouse designs require double glass panes, ground insulation, and insulation of the common wall on the interior side of the house, so that the house does not lose heat to the greenhouse at night.[10] To prevent the attached greenhouse from becoming a net heat loser, insulation for the glazed area is required at night. To prevent overheating during the summer, only half of the roof depth of the greenhouse should be glazed to accomplish some shading, and there should be adequate ventilation to the exterior.

This type of passive system requires a south-facing glass enclosed collection space thermally linked to a thermal storage mass, and with an interface to the house to allow radiative, convective or conductive heat gain. The addition of a sunspace to an existing dwelling has great retrofit potential, given an optimal orientation and the absence of physical barriers causing shading during the winter, and can be integrated into a house design in the form of a glazed court or atrium or added as a lean-to (see Figure 9). Long, narrow shapes facing south allow the sun to reach the back wall of the greenhouse/sunspace, heating all of the space. Recommended length to width radios for a greenhouse in lower Canadian latitudes are between 2.0 and 1.5:1.0. The greenhouse

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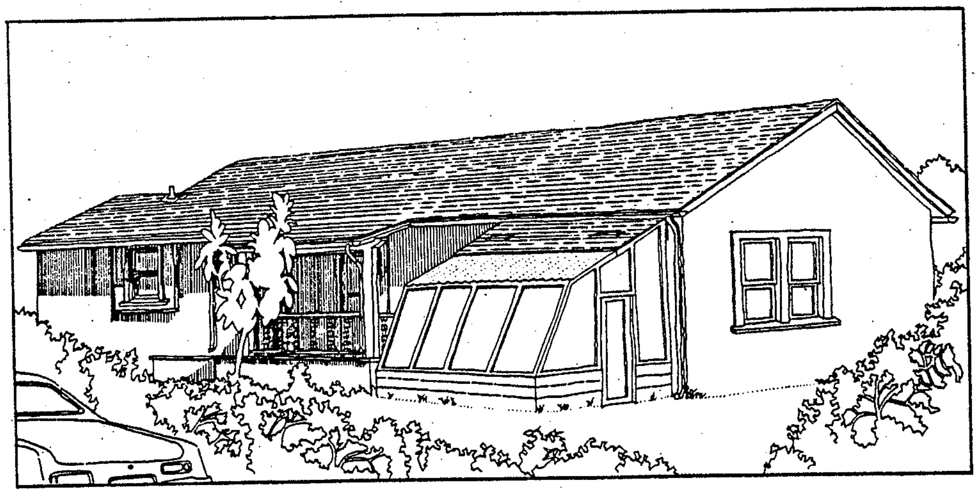
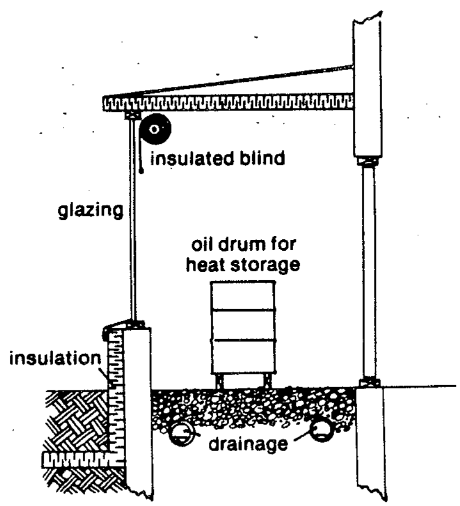
10 Hannah Pavlik, p. 2.



A house with a retrofit solar greenhouse.



The greenhouse can either be attached or free standing. Where it is attached to the south wall of a building, the heat surplus obtained on very sunny days can be used for heating the building.

The design of the greenhouse should also involve several energy conservation measures. These can include:

- insulated moveable shutters
- insulated foundations and ground
- air tight construction
- solid insulated north wall

Sources: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley, California, 1980), P. 64.

Solar Heating Catalogue No. 2., (Energy, Mines and Resources Canada, Ottawa, 1979), P. 64.

FIGURE 9: ATTACHED SUNSPACE/ GREENHOUSE

can be oriented within 45° to the east or west of south, but an optimal orientation would be between 15° and 30° east of south, to minimize overheating during summer afternoons with a westerly orientation.[11]

2) Indirect Gain Systems:

(i) Mass Wall:

A glass covered mass wall collects and stores heat directly from the sun, then later transfers heat "indirectly" to the building space primarily by means of radiation, but also by convection-controlled air dampers. This system requires a south facing glass wall with double or triple glazing to prevent heat loss, and a thermal storage mass of either masonry (Trombe wall) or water (tube wall). If these mass walls are contained within the living space, such as with water columns or rack-mounted water drums, these are more correctly classified as "direct gain" systems as they are not external to the living space.

A Trombe wall system utilizes an exterior storage mass of masonry or concrete, with appropriate time lag of heat transfer, providing heat to the building interior by radiation and possibly convection. Vents with dampers can be located at the top and bottom of the Trombe wall to control convective heat gain into the living space. Exterior insulating devices can also be provided for the exterior glass to diminish night-time heat loss, and control of overhangs can prevent unwanted summertime

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11 "Attached Solar Greenhouses (Sunspaces)," Lloyd Walker, (Colorado State University Extension Service, Fort Collins, Colorado, January 1980), p. 1,2. This criteria of orientation is explained diagramatically in Section 3.3 "Criteria for Residential Retrofit".

heating of the thermal storage mass (unless it is being used as a means of hot water pre-heating which would be required in the summer).

Trombe collector walls have achieved seasonal efficiencies of 30 to 35%, comparing favourably with the seasonal performance of active solar heating systems.[12] One interesting characteristic of the mass wall systems (masonry or water) is the heat capacity and transfer time lag of heat transfer by radiation to the adjacent building space air. Figure 10 illustrates the time-lag transfer effect for a 8" concrete block storage wall and for a 4" water wall (which has characteristics similar to a 10" water can storage system). These performance charts were developed by monitoring passive solar homes in Davis, California. One interesting aspect of these tests was that increasing the thickness of a concrete block storage wall beyond 8" (245 mm) did not result in any increase of heat storage capacity.[13]

Retrofitting of the mass wall system to existing houses is particularly suitable for older brick or stone wall construction of sufficient thickness, which can then be covered by a glass wall curtain (facing south) with an air space between and the optional use of dampers to allow heat transmission by convection, in addition to radiative heat transfer.

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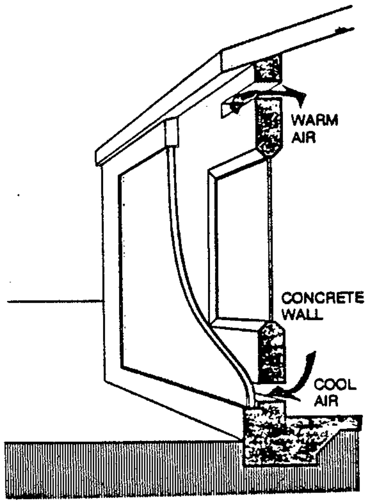
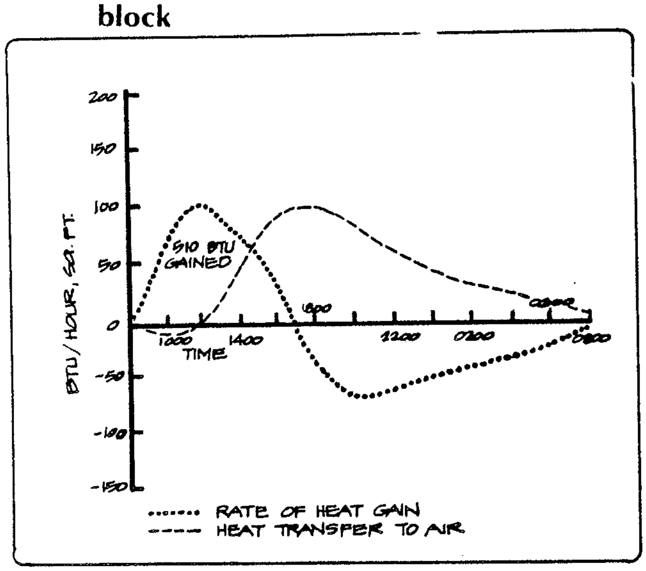
12 Bruce D. Gough, p. 38. "Efficiency" is defined as the ratio of collected energy to incident or available energy, and is a measure of the performance of a system. Highly efficient systems collect a greater percentage of the incident (available) solar energy striking the collector surface.

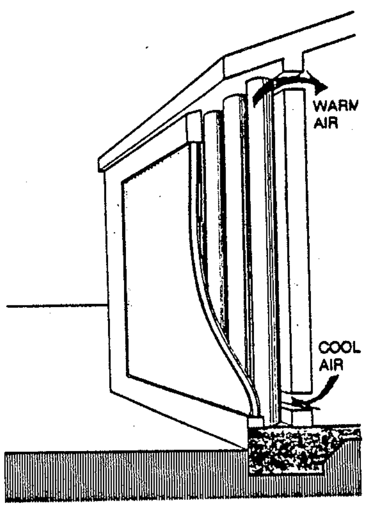
13 Davis Energy Conservation Report: Practical Use of the Sun, (Dept. of Housing and Urban Development, Washington, D.C., April 1977), p. 81.



The Trombe wall. The window allows some direct solar heating to supplement what flows through the wall and the hot air that rises into the living space through the top vents. Double glazing keeps heat losses low.

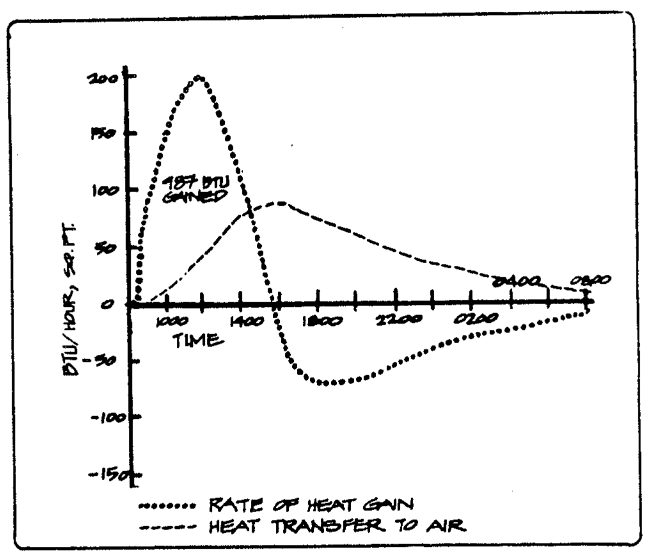
Heat Capacity and Transfer of a 8" concrete block





The tube wall. The double-glazed, black irrigation pipes or steel culverts absorb the sunshine and the water in them warms up. When heat is needed, air is blown behind the tubes and picks up heat from them. This system would provide more heat if it had shutters that are closed at night to prevent heat loss. In the Bay Area, though, the shutters cost more than the additional energy output is worth, so we recommend double glazing.

Heat Capacity and Transfer of a 4" water wall



Sources: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley, California, 1980), P. 62 & 63.

Davis Energy Conservation Report: Practical Use of the Sun, (U.S. Department of Housing and Urban Development, Washington, D.C., April 1977), P. 80 & 82.

FIGURE 10: MASS WALL STORAGE SYSTEMS

(ii) Mass Roof System:

Indirect gain mass roof systems, or roof ponds, consist of a pond of water enclosed in dark plastic (to absorb solar radiation) laid upon horizontal metal ceilings.[14] Roof shutters above the pond permit solar radiation gain during winter days, which is then re-radiated down into the living space at night when the roof shutters are closed. This system can also be used for cooling in the summer when the process is reversed, and the water absorbs excess heat from the interior. However, this system requires high winter sun angles and clear skies to facilitate radiative summer night cooling. These factors, combined with a high cooling load, make these systems most adaptable for areas of the south-western United States without night-time frost and not adaptable in Canada due to low night-time temperatures and seasonal freezing.

This system is probably the least adaptable of the passive system types to existing house construction, as it requires extensive roof support modification and mechanical (or manual) activation of the roof shutters for opening and closing.

(iii) Isolated Gain Thermosiphon System:

An isolated solar gain system is often used when the best orientation cannot be achieved by incorporating the system into the house, due to lack of collector surface area or shading effects.

The isolated heat gain system utilizes the principle of convection, either with a liquid or a gas, allowing the heated water or air to rise

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14 Bruce D. Gough, p. 40.

while being replaced by cooler water or air in a convective loop. This system can be used for the preheating of domestic water if the hot water tank is located above the collection area, as no mechanical means are used to pump the water. This type of system is similar in appearance to an active hot water system, except that a thermosiphon system is usually located at ground level at the base of a house wall in order to be below the storage tank of the transmitting medium (see Figure 11).

Themosiphon water systems may not be easily retrofitted to existing houses if the hot water tank requires relocation from the basement to the first floor or attic, or if solar access is not available down to the base of the house due to the casting of shadows from the low angle of the winter sun. In addition, if this isolated gain system is located away from the building in order to gain proper solar access, there is a problem of heat loss between the unit and the house during the winter. This type of isolated gain system, however, is more likely to be an "active" system with mechanical means of pumping and storing the heated fluid or gas, as a thermosiphon must be located adjacent to the space or water tank to be heated in order for the convective loop principle to operate efficiently.

Site-fabricated air thermosiphon systems producing low temperature (20-30°C) heat for space heating can be built into a house, but require careful thermal planning of the location of all components and controls. To prevent reverse thermosiphoning heat storage must be placed above the collector area, while the heat storage area should be ideally located below the space to be heated.[15] When combined with an electric fan to

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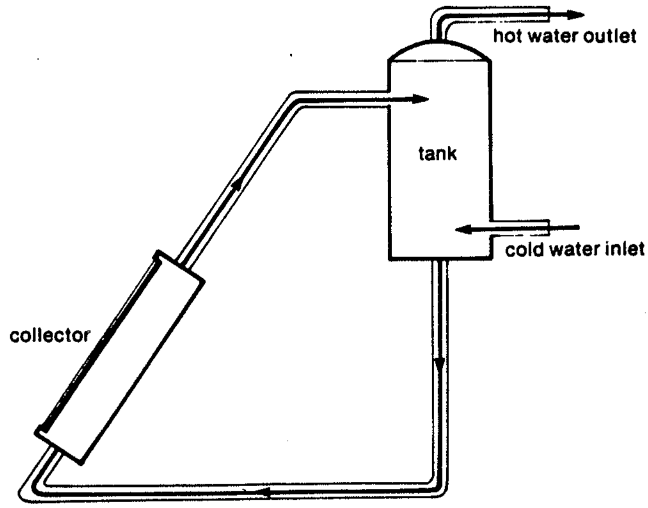
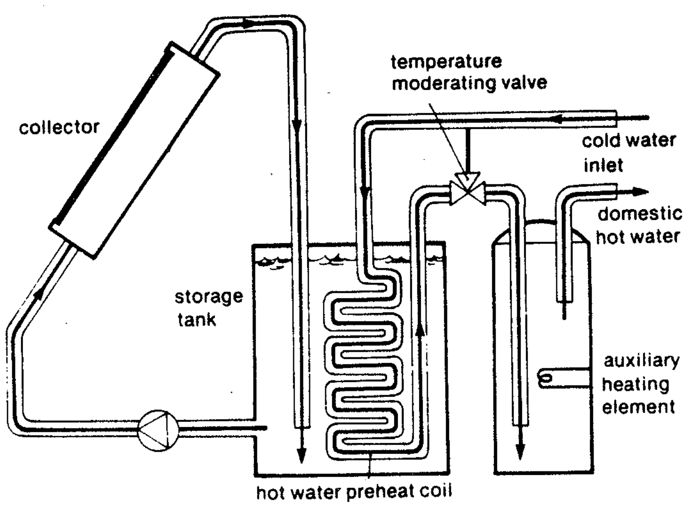
15 Bruce D. Gough, p. 42.



Thermosyphon Water Heater

With "forced" circulation, an outside source of energy (i.e., a pump or fan) is required to drive the fluid through the system. Although the thermosyphon option does not require additional energy, from the viewpoint of overall efficiency, it is probably better to install a small pump.



Solar Water Preheater

Sources: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley California, 1980), P. 5.

Solar Heating Catalogue No. 2., (Energy, Mines and Resources Canada, Ottawa, 1979), P. 57.

FIGURE 11: ISOLATED GAIN THERMOSIPHON SYSTEM

draw the heated air from storage, this becomes essentially a hybrid of the active air system - the only difference being that the convective loop principle requires the location of the collector area to be below that of the storage area.

2.5 ACTIVE SOLAR ENERGY SYSTEMS

2.5.1 Definition and Components

Active solar systems utilize similar principles of heat collection and storage as passive systems, but require mechanical assistance for heat transfer from collector to the storage unit, and from storage to the living space. Active solar systems are based either on liquid (water, or water and glycol) or gas (air) as the thermal transfer medium, and are generally more sophisticated than passive systems.

There are four main components to an active system:

1. collector
2. storage
3. distribution and controls
4. auxiliary energy supply.

In typical heating and cooling systems, solar energy incident on a collector surface is converted to thermal energy in a working fluid (commonly water or air). This working fluid delivers the heat energy to thermal energy storage equipment and then to the building space, to heat-operated refrigeration equipment for space cooling, or to heat water for use in the building.[16] In addition to these solar heating

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16 Solar Energy: Project Independence, p. I-15.

system concepts, several "hybrid" systems have been developed to use solar heat in conjunction with heat pumps to produce a moderate temperature heat source (50°F) from which heat can be extracted, or to drive a reversible mechanical heat pump to provide heating or cooling.[17]

Most active systems, as with passive systems, incorporate some form of auxiliary heat to provide for prolonged periods of low solar insolation and/or high heat demand. It is technologically possible to design a solar energy system to fully meet a building's space and water heating requirements, but studies have indicated that is not currently cost-efficient.[18] Short-term demand (2-3 days) can be achieved with an active system designed to meet a fraction of the total heat demand (20 to 70% depending on the system type and climate), supplemented by a backup heating system using conventional fuels such as oil, natural gas and electricity. The degree to which solar heating is supplemented by auxiliary energy sources will have implications for the planning of capacity by the utilities (natural gas and electricity) and the continued market presence of home oil.

Figure 12 illustrates the components used in an active solar energy system and the schematic flow of heat energy by which a system operates. The parts of a solar system - collector, storage, distribution and controls, and auxiliary energy supply - may vary widely in design, operation and performance. These components may be arranged in numerous com-

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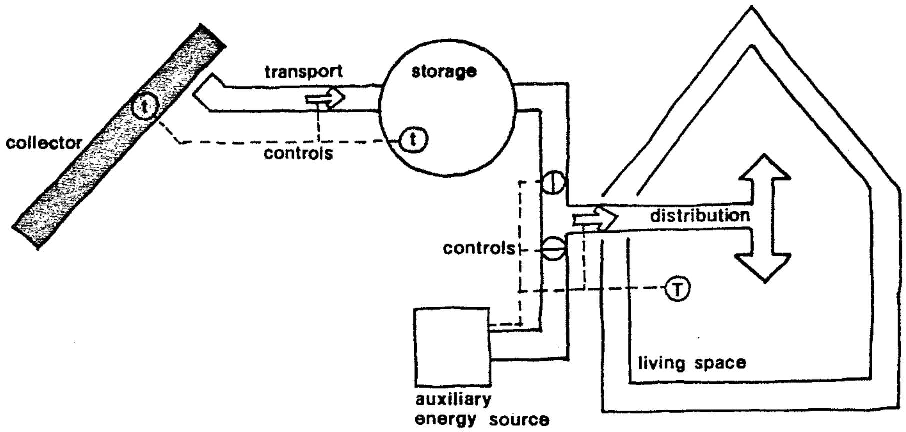
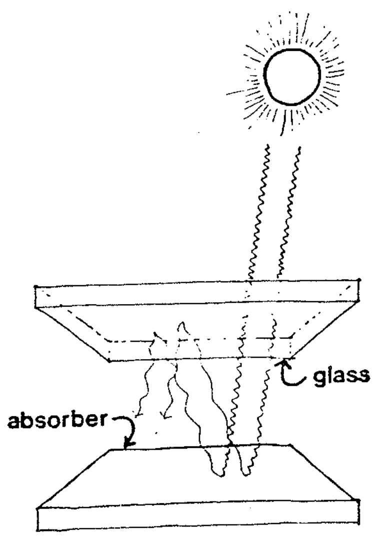
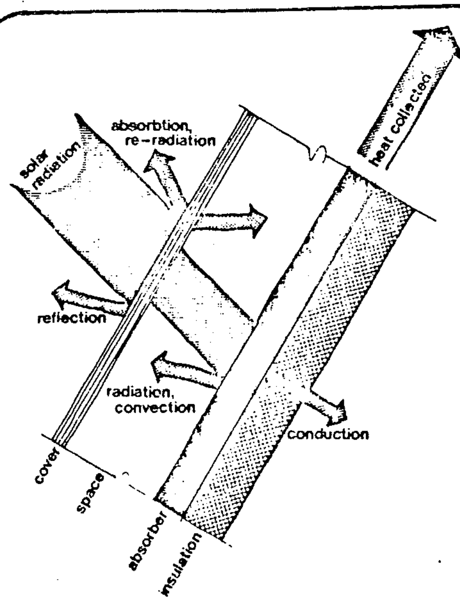
17 Solar Energy in America's Future: A Preliminary Assessment, p. 15.

18 Implementing a Solar Technology in Canada: Summary, M.K. Berkowitz, (Energy, Mines and Resources Canada, Ottawa, 1978), p. 1.



Active solar energy system.





Sources: "Solar Energy: Applied to Rural Housing," (Blaine G. Marler, Home and Community Design Branch, Alberta Agriculture, Edmonton, 1977), P. 2 & 3.

"Solar Energy Technology," Energy Conservation Handbook, (Royal Architectural Institute of Canada, Ottawa, 1979).

FIGURE 12: ACTIVE SYSTEMS: OPERATIONAL PRINCIPLES AND COMPONENTS

binations dependent on function, component compatability, climate conditions, required use and performance, site characteristics, and architectural requirements imposed by the building itself.

1) Collector: consists of an absorber plate or tube, usually fabricated of metal and coated black to increase solar absorption. The collector is insulated underneath and covered by one or more transparent cover plates to trap heat and reduce convective losses from the absorber plate. The heat transfer fluid, usually water or air, is heated as it passes through or near the absorber plate and is then transported by mechanical means (pump or fan) directly to the point of use, or to storage, depending on energy demand.[19]

2) Storage: storage of the captured thermal energy is required to provide heat during the seasonal heating season, the length and amount of which varies by region. Heat is stored when energy delivered by the collector exceeds the demand at the point of use. Transfer to storage can be made by direct contact of the heat transfer fluid with the storage medium (water to water), or by means of a heat exchanger (most commonly water to air).

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19 Solar Hot Water and Your Home, National Solar Heating and Cooling Information Centre, Rockville, MD, (date unknown), p. 2.

3) Distribution and Controls: the distribution component receives heat energy from the collector or storage, and distributes it at points of use as hot water for space and/or water heating needs, or as heated air for space heating (forced air distribution). The controls perform the sensing, evaluation and response functions required to operate the system in the desired mode, thus maintaining the occupants' comfort level.[20]

4) Auxiliary System: is required when the stored supply of energy is depleted by lack of insolation or if energy demand exceeds the collected energy (very cold weather), unless there is 100% seasonal storage capability.[21] The back-up heating system provides heat until collected energy again matches or exceeds energy demand.

No one system has evolved from all of these possible combinations of collector types, heat transfer mediums, storage types or auxiliary systems. However, it is likely that certain system types will evolve to meet specific building types, geographic location, and predominant back-up source of energy, in order to maximize collector efficiency and become cost-effective on a life cycle basis.

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20 Solar Hot Water and Your Home, National Solar Heating and Cooling Information Centre, Rockville, MD, (Date Unknown), p. 2.

21 Seasonal storage collects a large portion of the heat in the summer when solar insolation is at a maximum, and stores the energy in large water tanks. This concept is most applicable to group heating applications involving large-scale central storage.

2.5.2 Generic Types and Operational Principles

This section presents the range of generic types and their characteristics, and analyzes in detail those systems most applicable to residential space and water heating. There are a number of active solar energy systems that are currently being marketed, ranging from low-cost flat plate air or water systems to highly technical, expensive parabolic focusing and tracking collectors.

Active systems can be classified by their collector type (flat-plate, evacuated tube, focussing, tracking), their heat transfer medium (water, air), and their application (residential hot water, space heating, space and water heating). Table 7 summarizes the active system types currently available by these classification criteria and their typical end use. Of these systems, flat plate air or water systems, and evacuated tube systems to a more limited extent, are most commonly used in residential applications.

1) Flat-Plate Liquid Systems:

The flat plat liquid system using water, or a mixture of water and glycol anti-freeze, is the most common active system currently used. The flat plate collector has a solid, tube filled absorbing surface and energy is removed by the liquid transfer medium flowing through it. Alternatively, the collector can be a trickle-type allowing water to run openly down channels in the collector, but this method cannot be used in the winter due to freezing problems.[22] Storage consists of an insulated

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22 This method is commonly used for summer only heating of swimming pools.

Table 7: Active Systems: Generic Types

Collector Type*	Capture/Transfer Medium	Storage	Distribution System	Application
FLAT-PLATE (Tube or Trickle)	Water	Insulated water tank Water tank in rock bed	Hot water only Radiant pipe Forced air or heat exchange coil	Water and/or space heating
(Tube or Matrix)	Air	Rock bed Eutectic Salts	Forced air	Space heating
EVACUATED TUBE	Water	Insulated water tank Water tank in rock bed	Same as flat-plate	Water & space heating
FOCUSSING (Linear Focus)	Water or Photo-voltaic cells	Same as flat-plate	Same as flat-plate	Water & space heating
TRACKING (Central Focus)	Water Steam	Large central storage	Radiant heat & hot water (district)	Industrial & Utility
PHOTOVOLTAIC (Flat-Plate)	Silicon (or other) cells	Direct feed power storage cells	Electricity lines	Industrial & Utility Limited Residential

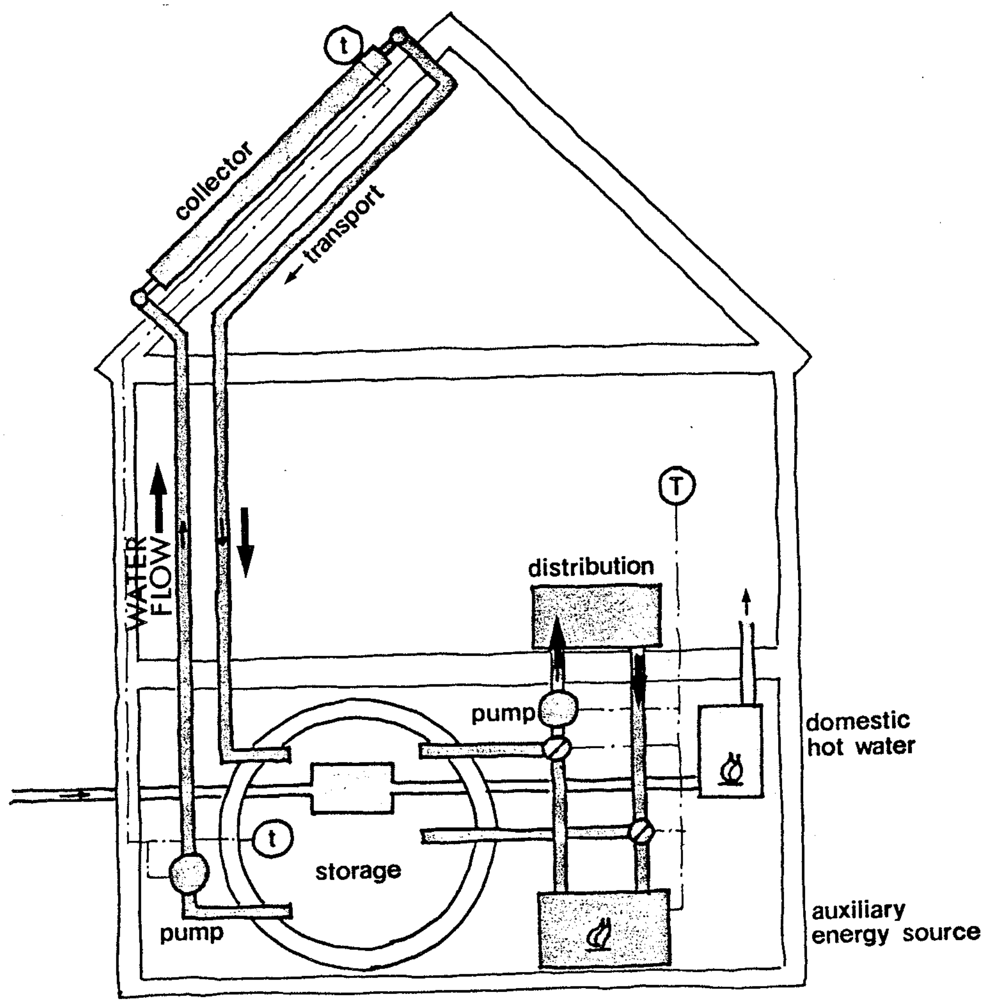
* in order of increasing technology and cost.

water tank approximately the same size as the existing hot water tank if the system is being used for hot water heating only, or a larger insulated water tank which can be buried in a rock bed for additional thermal capacity. Distribution for space heating is achieved by radiants (hot water pipes) or by means of a water-air heat exchanger to preheat a forced air furnace system. Sensors and thermostats monitor the system operation and an auxiliary energy source (usually the existing mode of heat supply) is required when energy demand exceeds the collected energy.

Sizing of the collector area will depend upon whether the system is used for water heating only, or for water and space heating combined. Collector areas of 50 to 100 square feet are common for domestic hot water heating in Canada, and usually do not present problems in terms of roof (or wall) space available for single-family dwellings if solar access is guaranteed in the winter. Liquid flat-plate collector systems used only for pre-heating of domestic hot water can provide up to 75% of the energy required, depending upon the collector efficiency and the daily hot water demand pattern. Figure 13 illustrates schematically two types of water systems: liquid flat plate space heating and domestic hot water supply. An alternative heat storage method is to place the water tank in a rock bed.

2) Evacuated Tube Collector:

The evacuated tube collector system is identical in principle to the liquid flat-plate system in terms of heat transfer medium (water), storage, and distribution. The collector, instead of being a tube or



Liquid flat plate space heating system.

Source: "Solar Energy Technology," Energy Conservation Handbook, (Royal Architectural Institute of Canada, Ottawa, 1979).

FIGURE 13: FLAT PLATE LIQUID COLLECTOR SYSTEM

trickle-type flat plate, consists of a long thin glass tube with an absorber (a tube through which the heat transfer fluid flows) inside it. A vacuum is created within the tube and the heat loss from the absorber tube is greatly reduced, resulting in a much higher collector efficiency than the flat-plate systems.[23] Thus, the ratio of collector surface area to living space (1:4 for flat plate) is reduced, and smaller usable roof (or wall) areas are required to produce the equivalent amount of heat provided by a flat plate water system. Alternatively, an even higher fraction (60%) of the space and water heating load can be provided but with diminishing returns on extra costs.

The evacuated tube collector system has significant retrofit potential for existing houses where the usable roof or wall area (with proper orientation and solar access) is not sufficient for a flat-plate collector system, and a usable solar fraction (40-60%) of the existing space and water heating load is still desired. However, capital and operating (i.e. breakage) costs may be higher than flat-plate systems.

3) Flat Plate Air Collector System:

Flat plate air collectors are typically used for space heating applications, and do not have the freezing problems associated with liquid systems. Water has a higher thermal storage capacity per unit volume, and thus air systems require large thermal storage (i.e. rock beds) in order to retain an equivalent amount of energy.

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23 Solar Heating Catalogue No. 2, (Energy, Mines and Resources Canada, Ottawa, 1979), p. 86.

The flat plate air collector has a solid absorbing surface and energy is removed by the transport medium (air) flowing in ducts below the absorber plate. Hot air is distributed directly to the living space or to storage dependent upon seasonal and daily heating demands. Storage consists of rocks 20 to 40 mm (3/4" to 1 1/2") in diameter in an insulated container, or by means of phase-change eutectic salts.[24] An auxiliary energy system provides back-up heat directly to the storage (i.e. electric resistance wires embedded in rock storage) or to the living spaces via conventional forced air ducts when space heat demand is not met by the collector system, as illustrated in Figure 14. Sensors and thermostats monitor the system to provide control and operate motors and dampers.

The use of phase-change eutectic sales as an alternate storage medium has interesting ramifications for storage retrofitting in existing houses. A rock volume of .15 cubic metres per square meter (0.5 cubic feet per square foot) of collector is required to provide adequate short term storage, resulting in a storage volume of about 200 cubic feet for a 1600 square foot, energy-efficient house. If this storage volume is not available in an existing basement or if it is too costly to excavate and place the rock storage container underground, then the smaller storage volume of eutectic salts is a suitable

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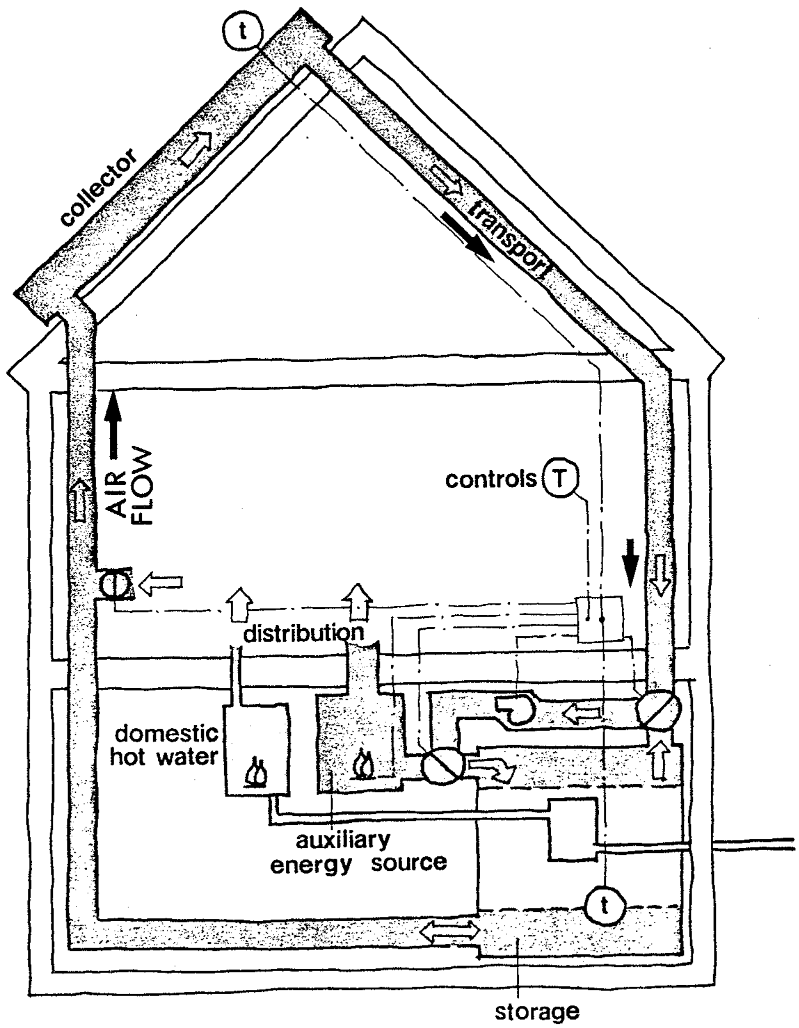
24 Blaine G. Marler, p. 7. Eutectic salts, mined in Saskatchewan, are mixed with chemicals, water and peat moss to improve consistency. The salts have the capacity to store heat until they reach a temperature which converts the eutectic salts to a liquid. During this "phase change" heat is released for space heating.



Air flat plate heating system.

Source: "Solar Energy Technology," Energy Conservation Handbook, (Royal Architectural Institute of Canada, Ottawa, 1979).

FIGURE 14: FLAT PLATE AIR SYSTEM

alternative.[25] The cost of phase-change eutectic or Glauber salt storage is about one-third that of rocks, requires less volume, but can require replacement due to a shorter storage "life" than rocks.[26] Houses retrofitted with such a flat plate, space heating-salt storage system can typically obtain up to 40% of their heating demands.[27]

2.6 SUMMARY

This chapter has presented the generic types of passive and active systems applicable to space and water heating (not including "direct" photovoltaic systems), and has defined the principles by which they work.

A passive system can provide a significant percentage of a building's space heating requirements if siting, structure, activity accommodation and cost are carefully considered. It should be noted that "while passive solar heating appears to be conceptually straightforward, it is thermodynamically complex and the development of mathematical models for predicting the performance of a passive solar heated building

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25 Ibid., p. 8. Air Collectors require similar ratios to flat-plate water collectors of 1:4 for collector area to living area for an energy efficient house. Thus, a 1600 square foot house would require 400 square feet of collector area and 200 cubic feet (400 x 0.5) of rock storage.

26 "A common problem with phase change materials is that after changing state a number of times, a breakdown in the chemical structure occurs and the phase change fails to occur. To prevent this, new materials have been developed where the phase change materials are contained with the cells of light weight polymer concrete." Source: Solar Heating Catalogue No. 2, p. 119.

27 "Architects staking their future on sun and salt," Edmonton Journal, A. Arbuckle, (Edmonton, August 15, 1980), p. G-1.

remains an obstacle to the industry-wide recognition and application of passive solar heating."[28] Complementary to the use of passive solar energy are conservation measures to reduce existing heating and cooling loads, so that the solar energy gained by passive means can contribute a larger percentage of a building's energy demand on a cost-effective basis.

With active solar energy systems proper sizing of all components and setting of controls is very important to overall system efficiency. Efficient, properly installed and maintained space and water systems can contribute from 40 to 60% of domestic heat needs in Canada. In order to provide this percentage of the heating load in an energy efficient house, a ratio of 1:4 for collector area (net of frame) to living space area is required. Existing housing stock with higher heat loads (less energy efficient) require more collector area and storage volume, two to three times as much in most cases.[29] Thus, the amount of usable roof (or wall) area with proper orientation <u>and</u> winter solar access required for a domestic space and water heating system of this nature may exceed the roof (or wall) area of an existing house. Either both roof and wall surfaces must be used as collector areas, or the consumer must accept a system that contributes a lower fraction of the house's heating load (i.e. domestic hot water only).

This illustrates the importance of thermally upgrading an existing house <u>before</u> examining the applicability of an active or passive solar heating system as an alternate energy source.

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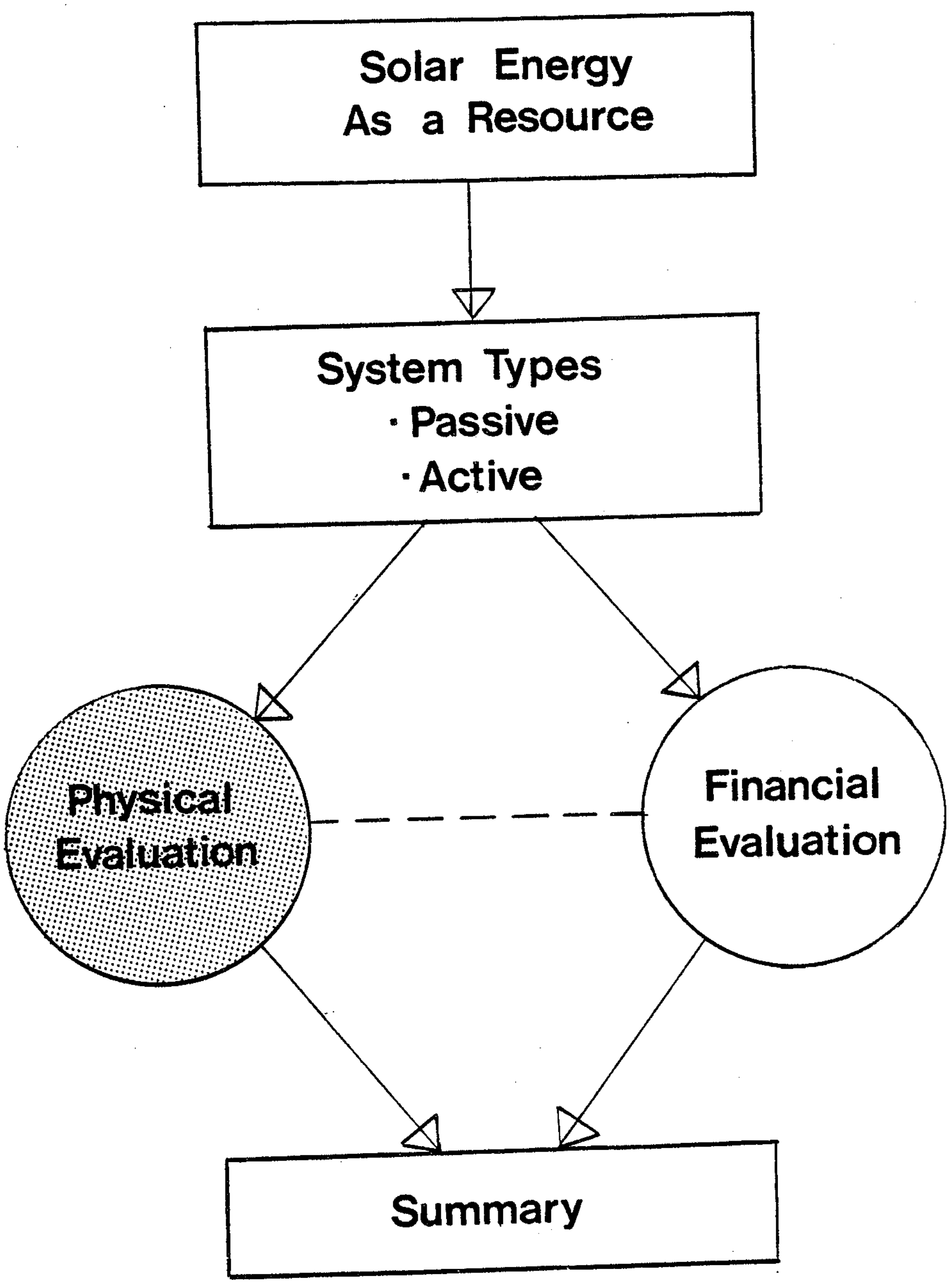
28 Bruce D. Gough, p. 3.

29 Blaine G. Marler, p. 9.

CHAPTER 3: RETROFIT EVALUATION OF SOLAR ENERGY SYSTEMS



STRUCTURE

3.1 INTRODUCTION

Most studies to date have focused on the application of solar energy to new housing design and subdivision layout, while minimizing the enormous potential of solar energy for the existing housing market given the growth rate and small percentage of new housing in the overall housing market.

Current constraints or barriers to the implementation of solar heating for the existing housing stock need to be identified so that appropriate policies and incentives can be created. Factors affecting the suitable retro-fitting of urban areas are illustrated by the results of a cross-Canada survey conducted by W.R.D. Sewell of the University of Victoria, indicating the ranking of barriers to the implementation of solar energy. Table 8 indicates that the cost of purchase and installation had a ranking of 1, and compatability with older structures had a ranking of 3 as wide-spread barriers to the successful implementation of solar energy. It is these two primary factors of physical retrofit and financial evaluation that this thesis will examine in the following two chapters.

Table 8: Perceived Barriers to the Wider Acceptance of Solar Space Heating in Canada

TYPE OF BARRIER	RANK
Financial	
Cost of purchase and installation	1
Public willingness to pay	2
Lack of federal support	4
Financial agency support	8
Possibility of higher property taxes	15
Comparison with other energy forms	17
Maintenance cost	20
Operating difficulties	25
Operating time	26
Social costs	27
Physical	
Compatability with older structures	3
Compatability with building techniques	9=
Availability of materials and parts	11
Inconvenience and time required to install	13
Climatic dependence	13
Institutional & Other	
Public environmental apathy	3
Availability of information	6=
Conservation of building trades	6=
Scientific support	9=
Difficulty of return to status quo	12
Lack of constructional skills	14
Legal factors, building codes	16
Credibility of advocates	18
Lifestyle impacts	21
Aesthetics	22
Impact on adoption of other innovations	24
Environmental Impact	28

= indicates an equivalent ranking. Rank 1 has the most importance.

Source: Derived from Table 2, _Solar Home Heating in Canada: Problems and Prospects_, H.D. Foster, W.R.D. Sewell, Ottawa, 1977.

For purposes of this thesis, barriers to the implementation of solar energy systems for existing housing will be categorized in the following manner:

Factors (Barriers)	Constraints (Sub-Factors)
1) Physical (Chapter 3)	a) Locational (ie. solar access) b) Institutional (legal mechanisms) c) Attitudinal (aesthetics)
2) Financial (Chapter 4)	a) Institutional (government/banks) b) Attitudinal (consumer confidence)

This differs from the W.R.D. Sewell classification in that "institutional" or "attitudinal" factors are seen as a constraint or sub-factors of the major factors of cost and physical barriers. For example, the existence or non-existence of legal mechanisms to protect solar access are institutional constraints to the physical implementation of solar energy systems.

Thus, chapter 4 on "Financial Evaluation" will incorporate institutional constraints affecting life-cycle costing and pay-back periods into the "Financial Factors" category -- such as mortgage rates and the inclusion of a solar energy system into a house's property tax assessment. In addition, certain "institutional" constraints will arise out of the case study analysis in Chapter 3, such as municipal zoning set-back requirements and lack of solar zoning protection, and will thus influence the policy conclusions reached.

The inherent challenge in the retrofitting of passive or active solar collection to existing housing stock, particularly older houses, lies in the identification of houses having optimal orientation to utilize solar collection, sufficient insulation levels, and the absence of physical barriers preventing shading of the solar collection "unit." As a result, the following Section 3.2 will outline the design considerations and major factors affecting the retrofit suitability of solar energy systems to existing housing stock. Section 3.3 will outline the criteria for choosing two residential study areas in Winnipeg, and Section 3.4 will examine specific retrofit criteria in detail with respect to the overall residential layout of the two study areas. Specific legal mechanisms to protect solar access will be outlined in Section 3.5, leading to conclusions and policy recommendations specific to each case study area - with extrapolation to the urban context of Winnipeg as a whole.

3.2 CRITERIA FOR RESIDENTIAL RETROFIT

The adaptability of the existing housing stock to active or passive solar systems is highly dependent on the interface between the system type and the type of dwelling to be retrofitted. Thus, design characteristics of a particular type of solar energy system will influence its location in or on the house, or even its feasibility. In turn, characteristics of the existing house will affect the choice of system and its operating efficiency. A number of retrofit criteria will be reviewed in terms of the active and passive system types and their characteristics, in order to determine a proper interface between system types and an existing house.

3.2.1 Criteria for Active and Passive Systems

The principal factors which influence, negatively or positively, the retrofit suitability of active or passive systems with respect to existing housing stock are:

1) Solar Access: (a) lot orientation
   (b) solar altitude
   (c) shading by adjacent buildings and/or trees
2) Roof Form/Angle
3) Heat Storage
4) Thermal Insulation
5) Heating System/Fuel Type

An additional criteria in terms of physical retrofit evaluation is the effect of building codes on the construction of solar energy systems. Items such as opening design, fire and electrical codes, roof design, mechanical components, etc. will influence both the feasibility of a solar energy system design and related construction costs - this is particularly true of retrofit cases. Moreover, building codes vary from municipality to municipality, and this will not be explored in detail in the case study evaluation to follow, as the criteria to be explored are intended to be more "universal" in nature.

The following table indicates the relationship between the factors listed above and active and passive systems, ie. whether or not specific criteria are important to the retrofit installation of a solar energy system.

Table 9: Retrofit Suitability Criteria

CRITERIA REQUIRED:	SYSTEM TYPE	
	Active	Passive
1) Solar Access:		
(a) lot orientation	Yes	Yes
(b) solar altitude	Yes	Yes
(c) shading by adjacent buildings and/or trees	Yes	Yes
2) Roof Form/Angle	Yes	Summer shading of glass collection surface (to some extent)
3) Heat Storage	Storage volume for type of active system	Thermal mass - passive heat retention
4) Thermal Insulation	Insulation levels vs. system efficiency	Insulation levels vs. system efficiency
5) Existing Heating System & Fuel Type		
(i) space	Yes (interface)	Yes (to some extent)
(ii) water	Yes (interface)	Yes (to some extent)

Each of these criteria will be reviewed in detail in the following sections with respect to active and passive system types, and the interface between system type and existing housing.

1) Solar Access:

"Solar access" is a combined function of lot orientation, solar altitude, and possible shading effects of adjacent buildings, roof forms, and trees. In order for wall or roof-mounted solar energy systems to be effective, uninterrupted access to solar radiation must be guaranteed during the winter heating season.

(a) Orientation: A collector orientation of 20 degrees to either side of true south is acceptable, with little drop-off in collector performance. Wider deviations up to ±30° of south are possible, with some reduction in drop off in collector performance of less than 10%, as indicated in Figure 15.[1] Collectors can be mounted on either south-facing wall faces or roof surfaces (or both) as illustrated in Figure 17.

(b) Solar Altitude: Typically, if solar access is not obstructed on December 22nd (winter solstice), the day on which the altitude of the sun is lowest during the year, then solar access will be guaranteed for the rest of the heating season.

The sun path chart in Figure 16 is representative of Winnipeg

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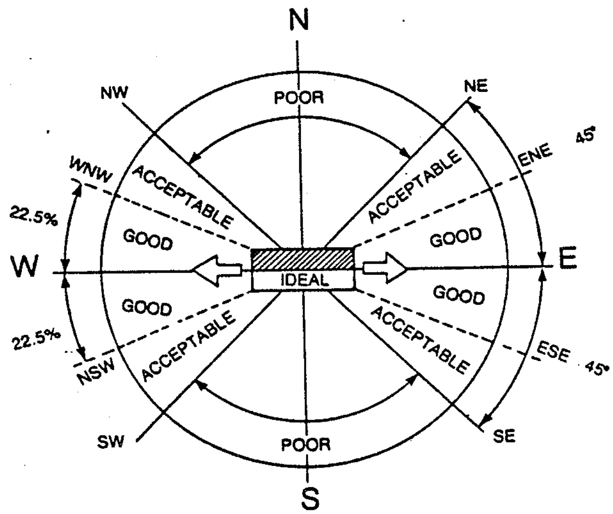
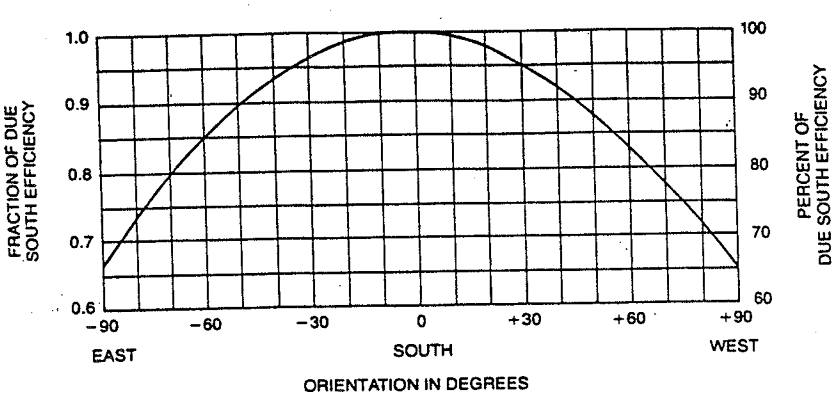
1 Solar Hot Water and Your Home, p. 4.

Long Axis Orientation for Detached Housing



45° VARIATION FROM IDEAL EAST/WEST ORIENTATION IS ACCEPTABLE, AND A MAXIMUM 22.5° VARIATION IS BETTER, TO ASSURE PROPER WINTER HEAT GAIN AND SUMMER SHADE CONTROL.

Effect of Solar Collector Orientation on Annual Heating Performance*



*Based on Colorado State University, Solar Energy Applications Laboratory, *Solar Heating and Cooling of Residential Buildings*, pp. 14-18.

Source: Site Planning for Solar Access, D. Eiley, et al., (American Planning Association, U.S. Government Printing Office, Washington, D.C., May 1980), P. 54 & 55.

FIGURE 15: COLLECTOR ORIENTATION

The sun path chart is a two dimensional record of the annual movements of the sun across the sky, for a specific latitude. The base line represents a flat horizon. The bottom arch is the path of the sun at the winter solstice (Dec. 21), the top arch is the summer solstice (June 21). Note that the sun traces the same path twice a year, as the days get longer, and as they get shorter. (For example, September and March are paired on the chart). Months are centred on the 21st day of each month.
Radial lines indicate the time of day (standard time). Time numbers are centered on each 'square'.
The number in each square indicates the fraction of solar energy (under perfect conditions) which occurs during a one hour portion, between ½ hour before, and ½ hour after, the time indicated for the 21st day of the month. The example plotted shows that on March 21/Sep.21 12% of the daily total solar energy falling on a vertical surface will occur (under ideal conditions) between 1:30 pm and 2:30 pm, local solar time. In this graph it is averaged, and assumed constant over a month. Local solar time is close to local standard time.

SUN PATH CHART 49° NORTH

HOURLY FRACTION OF DAILY TOTAL SUNSHINE

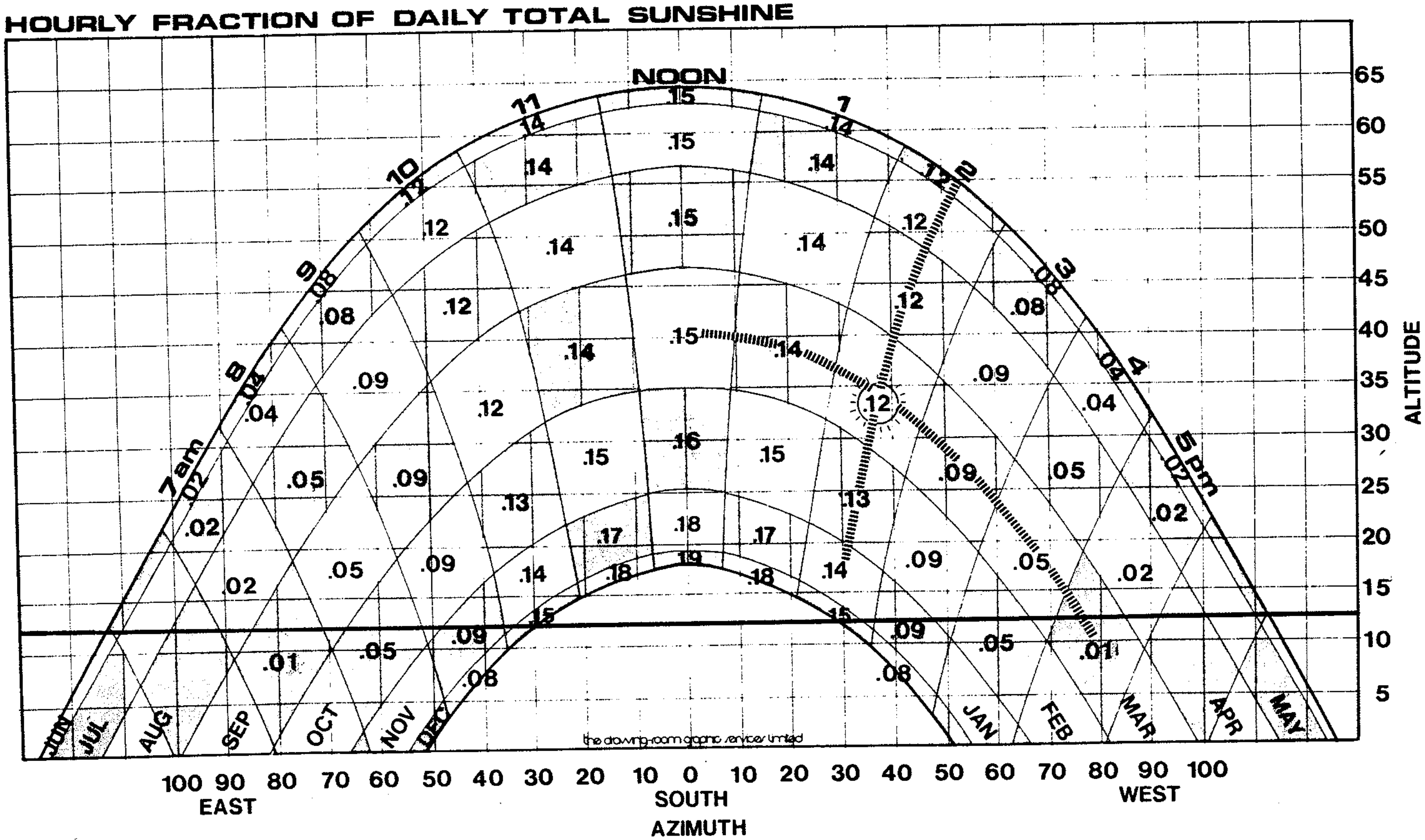
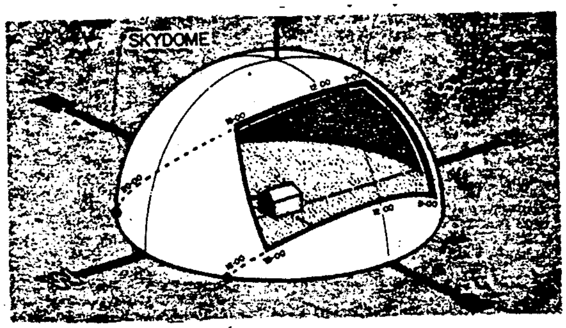


FIGURE 16: SUN PATH CHART 49° N.

Source: Solplan 2: Solar Energy for Existing Homes, R. Kadulski, et al., (Drawing-Room Graphic Services Ltd., Vancouver, B.C., July 1978), P. 12.



SUN WINDOW

THE SUN WINDOW IS AN OPENING CUT IN AN IMAGINARY SKYDOME. ANY OBSTRUCTION BY A NATURAL OR MAN-MADE OBJECT COULD MAKE AN ACTIVE AND/OR PASSIVE SOLAR SYSTEM INEFFECTIVE. THE SUN WINDOW IS A PHYSICAL REPRESENTATION OF "THE RIGHT TO SUN LIGHT".

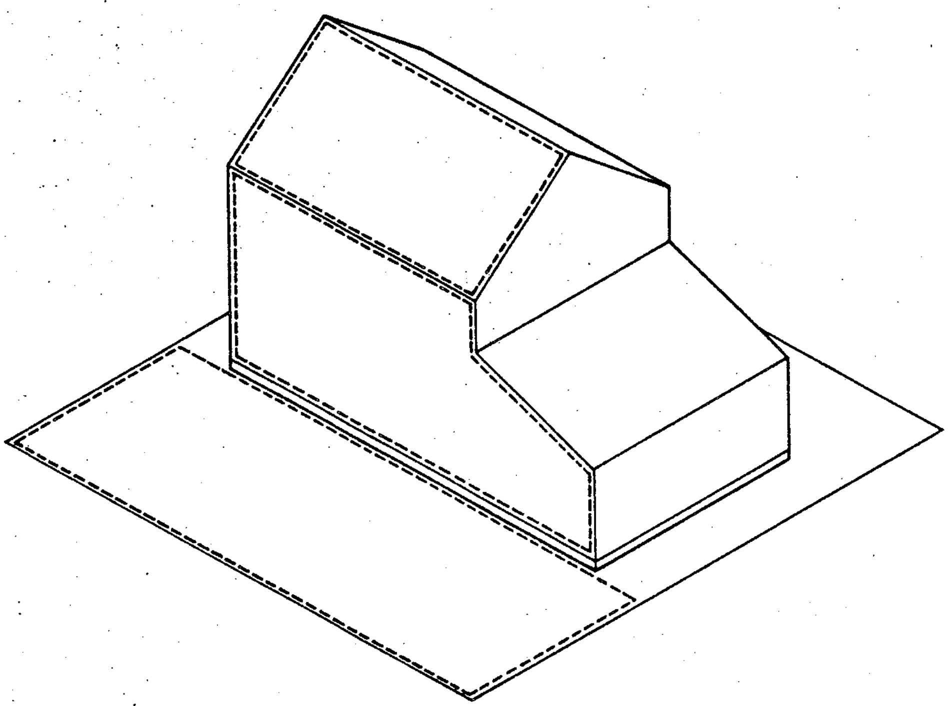


Figure **: Any smooth, generally south-facing area should be prospected. The dotted lines indicate possible collection areas.**

Source: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley, California, 1980), P. 38.

FIGURE 17: SOLAR ACCESS

(slightly north of 49°N.) and the "solar envelope" resulting from this sun path chart can also be used for other Canadian cities at or close to 49° latitude, i.e. Vancouver, Lethbridge, Regina, Thunder Bay, etc.. Cities north of 49° latitude (i.e. Edmonton) will require longer "solar envelopes" to guarantee winter solar access due to the lower altitude of the sun on December 22nd. Conversely, cities south of 49° latitude (i.e. Toronto) will require smaller "solar envelopes" to guarantee winter solar access, thus permitting closer spacing of houses (of equivalent height) than in cities further north. Figure 16 indicates that for a city located at 49° N. latitude, that the maximum solar altitude on December 21st will be 17.6°, and that the solar altitude on December 21st will exceed 12° only between 10 AM and 2 PM. This minimum solar altitude of 12° is the minimum solar angle at which solar energy can be collected efficiently.

Thus, a solar "envelope" can be defined for the winter solstice between 10 AM and 2 PM, with a maximum solar altitude of 17.6° at noon, into which no other building or object should intrude in order for solar access to be guaranteed for the winter heating season. Shadow patterns can then be developed for typical house heights (bungalow: 16', split-level: 20', and 2-storey: 26') for the winter solstice. Specific shadow patterns or "solar envelopes" for two Winnipeg case study areas will be developed in Section 3.4, showing the relationship between building height, lot orientation and shadow pattern. Figure 17 illustrates the concept of a "sun window" showing the three-dimensional solar access requirements for active and passive solar systems, over which shading by adjacent buildings and/or trees should not intrude.

(c) Shading: Solar access to the collector area should be guaranteed between 8 AM and 3 PM (or above a minimum solar angle of 12° to the horizon) on December 21st. Solar access can be affected by shading from adjacent coniferous trees, houses or buildings, reducing the usable collector area or blocking it entirely. Positive shading may occur where deciduous trees shade space-heating, wall-mounted active collectors in the summer (when they are not required). Objects obstructing solar access during the winter heating season when the altitude of the sun is low are usually other buildings (adjacent houses or high-rise buildings) or trees casting shadows. Coniferous trees located to the south of a house can effectively reduce the amount of solar radiation incident on a collector surface, reducing a solar energy system to a marginal or non cost-effective status. While deciduous trees lose their leaves during the winter heating season, the loss of leaves for certain tree species may not correspond to the start of the heating system, or dense branch patterns of certain species may reduce winter solar radiation incident on a collector surface by as much as 50%.[2] This will be dependent on the location of the tree (or trees) in relation to the house's solar collector area, the species type, its height (maturity) and individual branch pattern, as indicated by Figure 18.

2) Roof Form:

Active systems for the provision of domestic hot water have maximum

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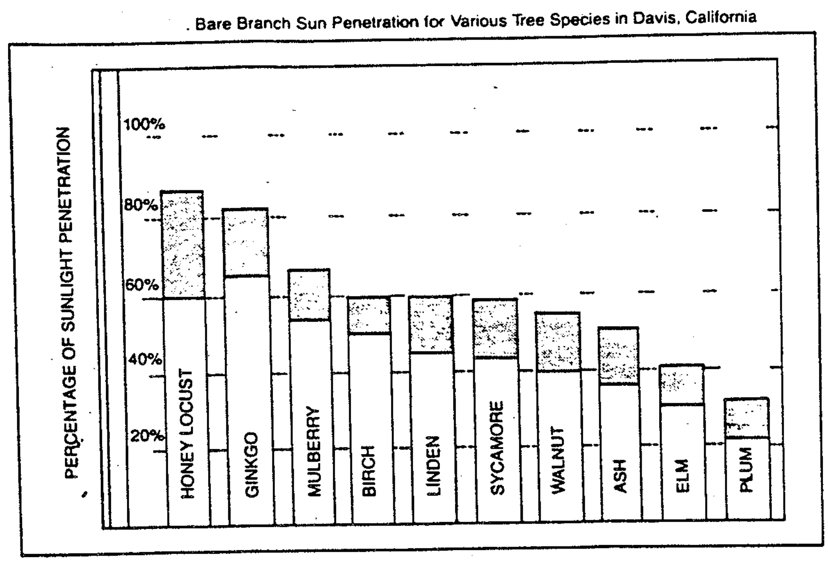
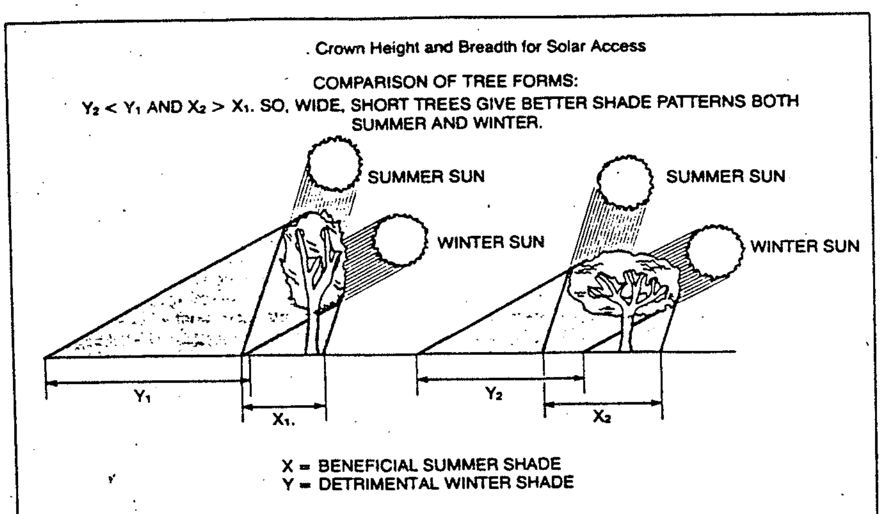
2 Source: Professor John Welch, Department of Environmental Studies, Faculty of Architecture, University of Manitoba, Winnipeg.





Source: Site Planning for Solar Access, D. Eiley, et al., (American Planning Association, U.S. Government Printing Office, Washington, D.C., May 1980), P. 94 & 96.

FIGURE 18: SHADING BY TREES AS A FUNCTION OF HEIGHT AND SPECIES

collector efficiency when tilted at an angle to the horizontal equal to the latitude (eg. Winnipeg = 50°), although there is no major drop-off in collector efficiency ±20° of the latitude angle (eg. Winnipeg, 30° to 70° tilt angle).[3] Active systems for the provision of space and water heating have maximum collector efficiency when tilted at an angle equal to the latitude plus 15° (Winnipeg, 65°) so as to be near perpendicular to the December 21 noon elevation of the sun (18°) which is the mid-point of the heating season. Thus, the roof angle of an existing house may or may not be amenable to optimal collector tilt. If not, angled frames may have to be built between a flat or shallow roof to raise the collectors to an optimal tilt angle, increasing the cost of retrofitting and creating possible wind-loading problems.

Multi-level roofs on a house may cast shadows on some parts of the roof, thereby reducing usable collector area, as illustrated in Figure 19. Large (south-facing) areas free from obstructions (chimneys, vents) are needed to provide usable areas for collectors. Collector areas required by flat-plate water or air collectors for space heating purposes may exceed the usable roof area, thereby limiting the type of system. In addition, roofs may require structural strengthening in order to bear flat-plate water collectors which are heavier than flat-plate air collectors.

To summarize, the following factors must be taken into account when locating and designing solar collectors for roof surfaces:

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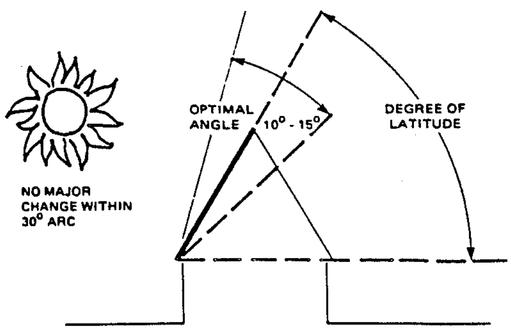
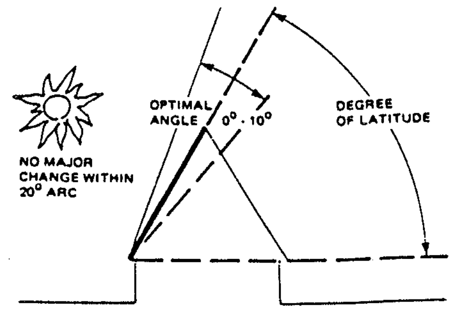
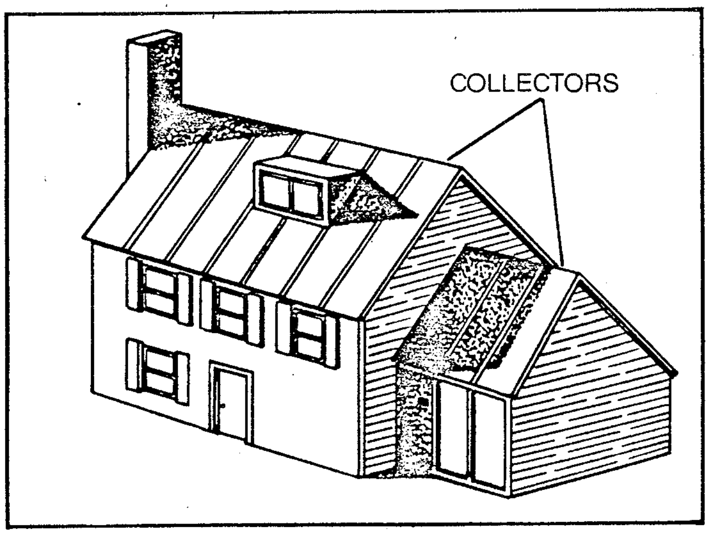
3 See Figure 19. A minimum collector tilt angle of 40° is required to induce avalanching or snow run-off from the collector surface, so that collector efficiency will not be affected in the winter.



COLLECTOR TILT FOR SPACE HEATING



COLLECTOR TILT FOR WATER HEATING



Shading of Collector by Building Elements. Chimneys, parapets, fire walls, dormers, and other building elements can cast shadows on adjacent roof-mounted solar collectors, as well as on vertical wall collectors. The drawing to the right shows a house with a 45° south-facing collector at latitude 40° North. By mid-afternoon portions of the collector are shaded by the chimney, dormer, and the offset between the collector on the garage. Careful attention to the placement of building elements and to floor plan arrangement is required to assure that unwanted collector shading does not occur.

Sources: Solar Energy, (B.C. Hydro, Energy Conservation Division, Vancouver, B.C., April 1980), P. 4 & 7.

Turn on the Sun, (Ontario Ministry of Energy, Toronto, October 1978), P. 12.

Solar Hot Water and Your Home, (National Solar Heating and Cooling Information Centre, Rockville, Maryland, 1979), P. 5.

FIGURE 19: ROOF FORM AND COLLECTOR TILT

(i) The orientation of roof surfaces.

(ii) Shading of roof surfaces by the roof form itself (i.e. hip roofs, dormer windows, etc.).

(iii) Height and angle of adjacent unit roof forms causing shading of the roof surface.

(iv) Usable roof surface area that is optimally oriented and shade-free to allow installation of active solar collectors (flat plate or evacuated tube).

(v) The predominant roof slope and construction as it may affect the optimal solar collecting angle and type of installation (interface between collector and roof).

(vi) Roof form, i.e. eaves, may or may not assist in the summer shading of wall-mounted active collectors or passive glass collection surfaces.

3) <u>Heat Storage</u>:

Any solar energy collection system requires some degree of thermal storage in order to serve as a heat source when heat demand exceeds the immediate heat output of the collection system. Most heat storage volumes are sized to supply the equivalent of two to three days heat demand (i.e. space heating). Some space heating systems can be designed to include seasonal storage volumes, but these require very large "heat sinks" and are not cost-efficient for residential purposes. Seasonal heat storage volumes such as water tanks, collect excess heat energy produced in the summer and utilize the heat during the winter when there is a net heat demand. To date, large seasonal heat storage volumes have been used on a limited basis for commercial buildings in Canada, notably the Ontario Hydro building in Toronto and the Gulf building in Calgary.

Table 10 outlines the types and sizes of heat storage that can be used in residential solar retrofits, as a function of system type.

Table 10: Types and Sizes of Heat Storage Required

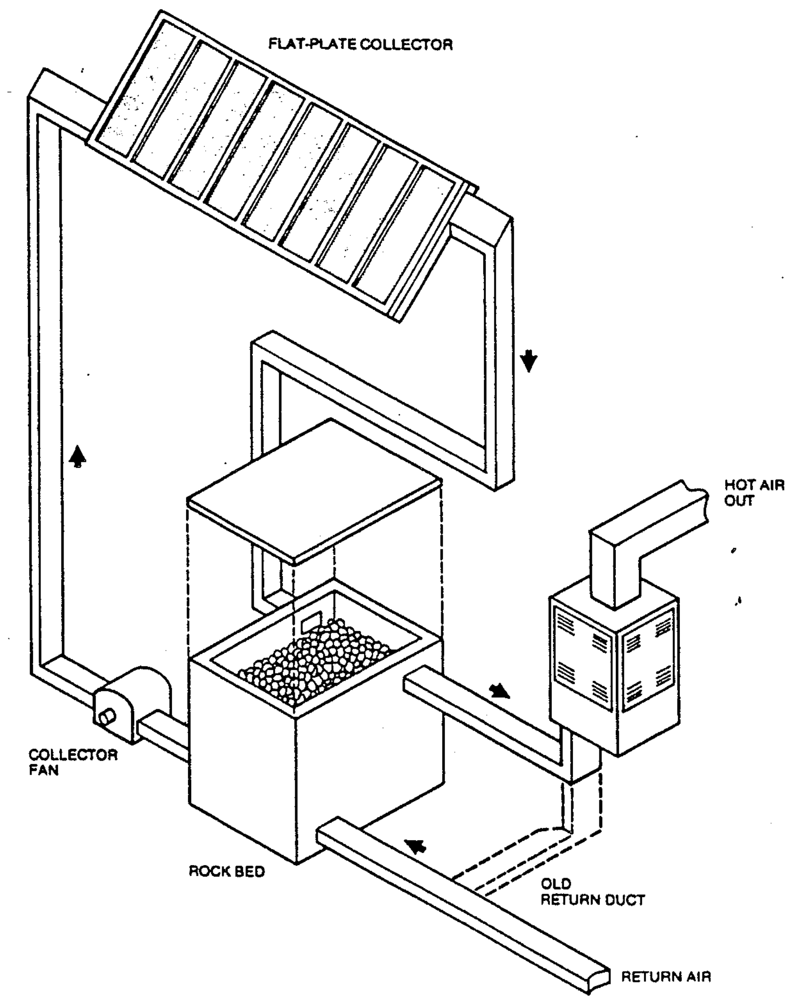
System Type	Storage Volume Required	Possible Location
ACTIVE		
(i) hot water heat	Water tank of equivalent volume to present hot hot water tank	Adjacent to mechanical room (basement)
(ii) space heat		
- water type:	Large insulated water tank chamber by itself or embedded in rock storage	Adjacent to mechanical room garage/shed (insulated). Buried in yard near home.
- air type:	Large rock bed storage	Adjacent to mechanical room (if sufficient space) under basement. Buried in yard near house.
PASSIVE		
(i) hot water thermosiphon	Water tank of equivalent volume to present hot water tank	Mechanical room or adjacent space
(ii) space heating		
- mass wall (Trombe)	Masonry wall 8" thick	Immediately adjacent to living space to be heated
- tube wall	4" water cube columns	(As above)
- window wall & sunspace	8" masonry floor & 8" masonry wall	In living space or adjacent

Depending upon the system type and its application, the storage volume and its location relative to the space (or water tank) to be heated can be a limiting factor in the choice of a solar energy collection system for retrofit purposes. Additional costs required to achieve the necessary storage volume may reduce a solar retrofit system to a marginal or cost-ineffective status, and the storage volume available may limit the percentage of total heat demand (i.e. 40% to 60% for space heating) that can be achieved.

Flat-plate air systems require considerably more storage volume (0.5 cubic feet per square foot of collector area for rock bed storage) than flat-plate water systems, unless eutectic salts are used. The choice of an air system for space heating may be eliminated in a retrofit application if sufficient volume is not available in the house for storage. Figure 20 illustrates the type and size of rock bed storage for an active air heating system. Domestic hot water systems require the least amount of storage volume (equivalent to the existing hot water heater) and are the easiest to retrofit.

4) Thermal Insulation:

The thermal efficiency of a house dramatically affects the fraction of the total heating load that can be met by an active or passive system. Energy inefficient houses may require collection areas and storage volumes greater than can be retrofitted into an existing house. Reducing infiltration, upgrading insulation and improving opening design should be a priority before evaluating the retrofit of an active or passive space-heating system to an existing house. This is a more



Schematic of an air flat-plate heating system. The system is inserted in the return duct before the furnace. Required dampers and controls are not shown.

Source: Solar For Your Present Home, C.S. Barnaby, et al., (Berkeley Solar Group, Berkeley, California, 1980), P. 71.

FIGURE 20: HEAT STORAGE VOLUME

important consideration for space-heating systems than systems used exclusively for domestic hot water.

This criteria of thermal insulation in existing houses will be examined in greater detail with respect to two Winnipeg study areas in Section 3.4.

5) Heating System/Fuel Type:

The existing space heating distribution system (radiant or forced air) may influence the choice of active water or air systems in terms of compatability; e.g. an air system is not compatible with an existing radiant heating system of an older house. The existing fuel (oil, gas or hydro) will dictate to some extent the size and cost of the system chosen due to its effect on the payback period.[4]

The types of heating systems (distribution) and fuel types for two Winnipeg study areas will be further examined in Section 3.4, with respect to compatability with active and passive solar systems.

3.2.2 Passive Systems: Retrofit Suitability

Retrofit suitability of the generic types of passive systems previously reviewed can then be examined in terms of the principal factors of solar access, orientation, heat storage (thermal mass) and insulation. Table 11 summarizes the advantages and disadvantages of the system types reviewed in Chapter 2 (direct window, sunspace, indirect

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4 The concept of payback periods is defined in Chapter 4 on "Financial Evaluation".

Table 11: Passive Systems Retrofit Suitability

	Advantages	Disadvantages
) **DIRECT**		
(i) **Window + Storage:**		
• Orientation & Solar Access	• Collection glass area provides light to living space and plants • Existing deciduous trees to south can shade window area in summer	• Window wall orientation to be within ±30° of south, preferably 15-20° of south • Summer glare and overheating without sufficient overhangs and controls • Existing coniferous trees to south may shade in winter
• Thermal Mass/Insulation	• Solar window wall is integral part of house construction • Can provide 30% or more of space heating load • Design flexibility • Standard materials available	• Conventional construction has low thermal mass and insulation • Internal walls and floor require large thermal mass and high thermal conductivity if south-facing window area > 6% of the floor area
(ii) **Attached Greenhouse**		
• Orientation & Solar Access	• Main house wall orientation not dictated by sun position • Plant growing capabilities • Existing deciduous trees to south can shade window area in summer	• Orientation of long face ±45° of south, preferably east of south • Should receive unobstructed sunlight from 9 AM to 3 PM in winter • Existing coniferous trees to south may shade in winter • Snow accumulation on sloped glass may reduce winter solar gain
• Thermal Mass/Insulation	• Good retrofit capabilities (reduces) infiltration and heat loss by conduction) • Can provide 30-50% of space heating load • Design flexibility	• Existing common wall may not have sufficient thermal mass • Large glass area requires night insulation and double or triple pane glass to prevent heat loss • May require additional heating if used for plants

Table 11: Passive Systems Retrofit Suitability (Cont'd)

	Advantages	Disadvantages
2) INDIRECT		
(i) Mass Wall:		
• Orientation & Solar Access	• Better protection from glare than direct system • Existing deciduous trees to south may shade in summer to prevent overheating	• Building orientation dictated by sun; usable collection wall to be oriented toward ±30° of south • Reduces direct natural solar gain and light available for interior spaces • Existing coniferous trees to south may shade in winter when solar gain required
• Thermal Mass/Insulation	• Time lag between collected energy and distribution to living space - controls less crucial • Exterior thermal mass wall can be integrated into light construction house design • Suitable for existing solid masonry wall construction	• Cavity and thin masonry wall construction not sufficient thermal mass for storage • Will not provide heat to non-adjacent living spaces unless additional forced convective distribution • Will overheat in summer unless insulated and shaded • Will lose heat during winter nights unless exterior insulated
(ii) Thermosiphon:		
• Orientation & Solar Access	• Building wall orientation not dictated by sun position as system can be positioned away from house	• If system is located at base of house wall, requires guaranteed solar access for south wall during winter 9 AM - 3 PM • System orientation to be within ±30° of south for collector efficiency • Existing deciduous trees to south may shade collector in summer when water heating is required
• Thermal Mass/Insulation	• Existing house may not require extra thermal mass due to isolated gain feature • Well suited to water heating, producing high water temperature	• If located away from house, separate storage mass required • Some heat loss between system and house during winter

mass wall, and thermosiphon) in terms of the principal "adaptability" factors of an existing house.[5]

Poor orientation and thermal mass (insulation or heavy mass construction) in an existing house may make the adaptation of a passive system only marginally cost-effective, while lack of solar access due to shading or very poor orientation may preclude the use of a passive system altogether. Lack of these criteria, however, do not necessarily mean that an active solar system cannot be used. For example, a roof mounted, active water heating system may be able to be used on a house which has poor wall orientation, shading of wall collection surfaces during the winter, and lack of thermal storage mass necessary for a passive space heating system.

3.2.3 Active Systems: Retrofit Suitability

As with passive systems, the retrofit suitability of active systems for the existing housing stock is highly dependent on the interface between the system type and the type of dwelling to be retrofitted. Design characteristics specific to an active system type will influence its collector area size and location on the roof or exterior walls, the size and location of its storage medium, and the distribution system required. In turn, the characteristics of the existing house will affect the choice of system, its application in terms of space or water heating, its operating efficiency and even its feasibility.

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5 Because the passive mass roof system is not well suited for Canadian latitudes, it will not be included in the retrofit suitability table. The issue of costs and benefits (i.e. payback period) will be discussed in Chapter 4 and is not used as a prime criteria for physical amenability.

Table 12: Active Systems Retrofit Suitability

System Type & Criteria	Potential Advantages	Potential Disadvantages
FLAT PLATE WATER:		
Domestic Water Only:		
1) Orientation:		• to be within ±20° of true south
2) Solar Access:	• can have some winter shading as it is a % of heating needs	• cannot be used if walls and roof shaded all year by obstructions
3) Roof Form:	• tilt angle = latitude ±20° means it can be mounted on low slope roof • collector area required is small	• collector tilt angle less than 40° may collect snow in winter
4) Storage Volume:	• small tank required	• piping between collector and storage should be minimized to prevent heat loss
5) Existing Heating:	• no interface problem with existing fuel supplying hot water heat • can reduce fuel cost by up to 75%	• does not provide space heating
FLAT PLATE WATER:		
1) Orientation:		• to be within ±20% of true south
2) Solar Access:	• deciduous tree shading in summer when space heating not needed	• potential shading by obstructions or roof form, critical in winter between 9 AM and 3 PM
3) Roof Form:		• tilt angle = latitude +15° requires steeper pitched roof (65°) • may require structural strengthening of roof • collector area required is large - "usable" roof and/or wall area may not be available
4) Storage Volume:	• medium-size storage volume required (less than air system)	

Table 12: Active Systems Retrofit Suitability (Cont'd)

System Type & Criteria	Potential Advantages	Potential Disadvantages
5) Existing Heating:	• compatible with radiant or forced air distribution (with heat exchanger), can provide 40-60% of heating needs	
FLAT PLATE AIR		
1) Orientation:		• to be within ±20° of true south
2) Solar Access:	• deciduous tree shading in summer when space heating not needed	• potential shading by obstructions or roof form, critical in winter between 9 AM and 3 PM
3) Roof Form:	• collector panels are lightweight, usually not requiring structural strengthening of roof	• tilt angle = latitude +15° requires steeper pitched roof (65°) • collector area required is large - "usuable" roof and/or wall area may not be available
4) Storage Volume:	• alternate eutectic salt storage volume is smaller, easier to retrofit	• rock bed storage volume is large and costly to retrofit • eutectic salt storage requires replacement after degradation
5) Existing Heating:	• compatible with forced air distribution systems • can provide 40-60% of space heating	• requires large air heat exchanger • not compatible with radiant wanter distribution system • cannot provide domestic hot water
EVACUATED TUBE (Water):		
Criteria 1), 2), 5)	Same as flat plate water collector	
3) Roof Form;	• requires smaller collector area due to higher efficiency	• 65° tilt angle requires steep pitched roof
4) Storage Volume:	• requires less storage volume than flat plate water due to higher collected temperatures	• higher collected water temperatures requires more controls

Table 12 summarizes the advantages and disadvantages of the active system types (flat-plate air or water, and evacuated tube) reviewed in Chapter 2, in terms of the principal criteria of orientation, solar access, roof form, heat storage and existing heating system.

3.3 CASE STUDY: SELECTION OF CASE STUDY AREAS

As an extension of the retrofit suitability criteria identified in Section 3.2 for passive and active systems, two study areas in Winnipeg were selected in order to determine what overall characteristics at the "neighbourhood" level would influence solar retrofit potential. Ultimately this type of study could be extended to an entire urban area, recognizing the fact that such factors as existing street layout, housing type distribution, housing age, and orientation will ultimately affect the solar retrofit potential for each area.

Two study areas were chosen in Winnipeg on the basis of the following criteria:

1) Lot Orientation: (a function of street layout):

   One neighbourhood to have predominantly east-west streets, resulting in a north-south lot orientation (longitudinal axis); the other neighbourhood to have predominantly north-south streets, resulting in an east-west lot or orientation (longitudinal axis).

2) Size:

   Each neighbourhood to be approximately the same area and density, with nearly equal populations (number of dwellings).

3) <u>Housing Type</u>:

Each neighbourhood to have approximately the same distribution of housing type, and to be reasonably close to the city norm in terms of distribution of housing type (single family, detached, row, etc.). A preference was indicated for neighbourhoods with a percentage of single-family dwellings higher than the city average, as higher density dwelling types use less energy per unit and the current potential of solar energy is greatest for single-family dwellings.

4) <u>Housing Age</u>:

Each neighbourhood to have approximately the same distribution of dwellings by housing age, and to be reasonably close to the city norm in terms of distribution by housing age.

5) <u>Neighbourhood Stability</u>:

Each neighbourhood to have higher than city average values for unit ownership vs. rental and for length of unit ownership. Neighbourhoods having these characteristics would have a higher than average potential for solar access), as retrofitting activity would more likely be biased towards home owners with low turnover rates.

6) <u>Availability of Data</u>:

The "neighbourhoods" chosen are administrative areas defined by the City of Winnipeg and thus have amalgamated data for the above criteria.

It should be noted that selection of two "neighbourhoods" (or administrative areas) having predominantly uniform street and lot orientations allows the study of representative smaller areas (i.e. several blocks or at the unit level) and the extrapolation of data or conclusions about these areas back up to the "neighbourhood" level. Newer subdivision areas of the city with multiple street and lot orientations would not be amenable to this type of sampling and extrapolation to a larger area, and would also not be as representative of city-wide existing housing stock on the basis of age and dwelling type.[6]

On the basis of the above criteria, two Winnipeg study areas were selected: Riverview and Sargent Park. Figure 21, "Area Characterization", illustrates the classification of areas by the City of Winnipeg - both Sargent Park and Riverview are classified as "conservation" areas and are approximately equi-distant from the downtown core. Both of these neighbourhoods exhibit the following characteristics:[7]

i) majority of housing stock is in good condition (60-70%)

ii) age of housing stock is beyond 25 years

iii) few redevelopment pressures

iv) a relatively high degree of self-sufficiency of the resident population

v) land/building values for the most part are stable

The City of Winnipeg's policy strategy for these areas is one of "minimal public capital support combined with selective minimum standards

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6 It is recognized, however, that newer areas are likely to have a higher percentage of energy-efficient housing stock and thus be more amenable to near-term solar retrofit.

7 "Winnipeg Area Characterization Study," Information Winnipeg, (Department of Environmental Planning, City of Winnipeg, July 1979), p. 2.

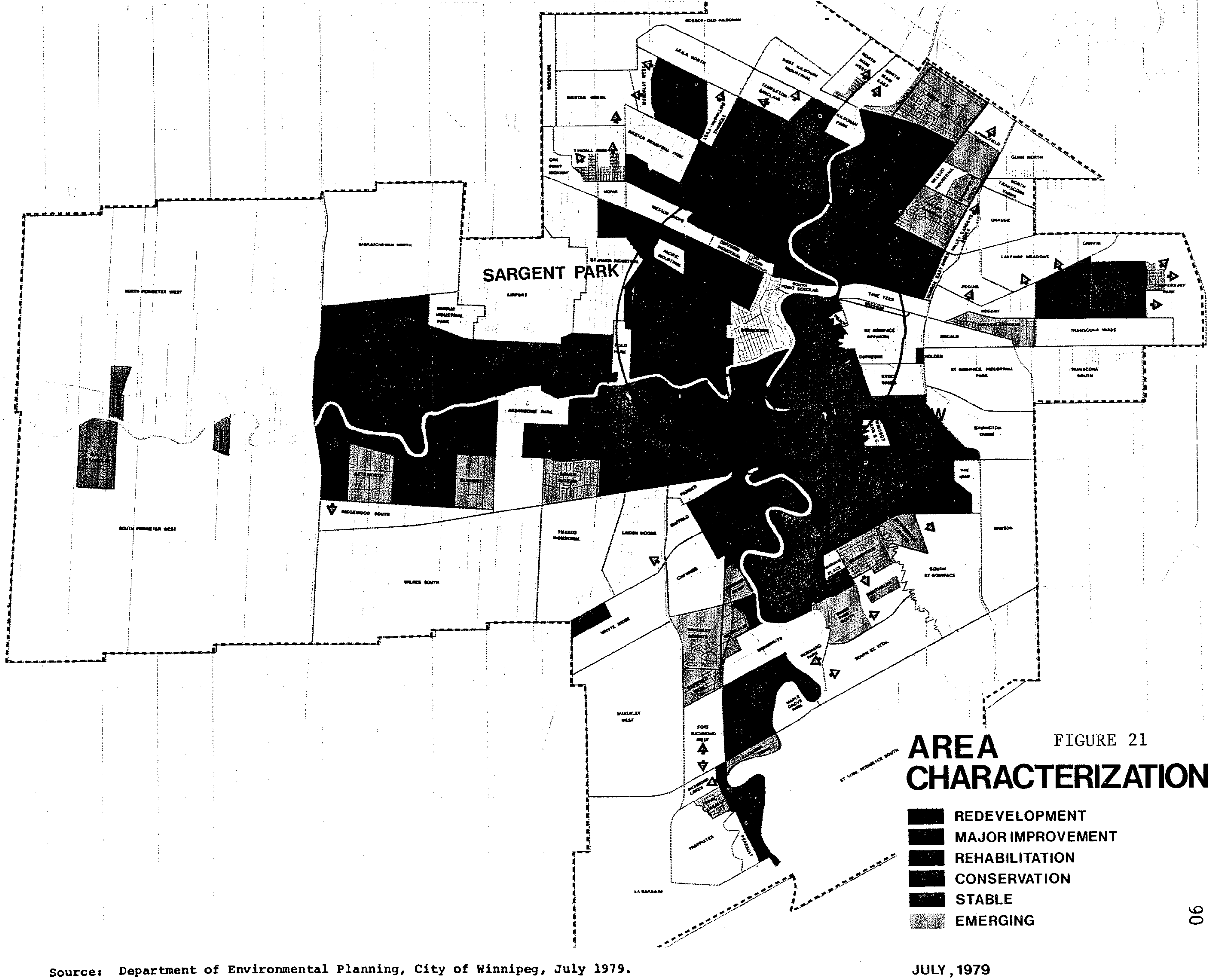

FIGURE 21

Source: Department of Environmental Planning, City of Winnipeg, July 1979.

code enforcement and incentives to encourage increased private capital support of the neighbourhoods."[8] Sargent Park and Riverview are both further characterized by values for unit ownership vs. tenancy and for length of occupancy above the city norm:

Table 13: Ownership vs. Tenancy (Private Occupied Dwellings), 1976

	Sargent Park		Riverview		City
	No.	%	No.	%	%
Owned:	1910	82.3	1360	75.9	58.1
Rented:	415	17.8	430	24.0	41.8
TOTAL	2325	100.0	1790	100.0	100.0

Table 14: Length of Occupancy, 1971 **(No. of Dwellings)**

	Sargent Park		Riverview		City
No. of Years	No.	%	No.	%	%
1	270	11.9	285	16.0	20.3
1- 2	260	11.4	195	10.9	16.1
3- 5	250	11.0	230	12.9	15.1
6-10	315	13.9	280	15.7	15.4
10+	1175	51.8	800	44.9	33.0
TOTAL	2270	100.0	1790	100.0	100.0

Source: Department of Environmental Planning, City of Winnipeg (Statistics Canada). NB: Totals may not match due to rounding of numbers to the nearest 5.

It can be seen that both areas have approximately the same number of dwellings (2325 vs 1970 in Table 15), and have quite similar distribution of values for length of occupancy and unit ownership vs. tenancy.

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8 Housing and Neighbourhood Strategies, (Environmental Planning Department, City of Winnipeg, August 1979), p. 18.

Table 15: Structural Type, 1976 (No. of Dwellings)

Structural Type	Sargent Park No.	Sargent Park %	Riverview No.	Riverview %	City %
Single Detached	1955	84.0	1400	78.2	57.5
Single Attached	35	1.5	20	1.1	6.3
Duplex	85	3.6	40	2.2	3.8
Apartment	245	10.5	330	18.4	31.9
Mobile	-	-	-	-	-
TOTAL	2325	100.0	1790	100.0	100.0

Source: Department of Environmental Planning, City of Winnipeg (Statistics Canada).

Values for the distribution by period of construction (age) will be presented in the next section as characteristic of thermal efficiency (one of the retrofit criteria) at the study area level. Thus, both areas are similar except with respect to predominant lot orientation, and other minor variations such as dwelling size (living area), roof form, and use of materials. These factors will be examined in detail in the next section on the retrofit suitability of the two case study areas.

3.4 RETROFIT SUITABILITY OF CASE STUDY AREAS

In Section 3.2, a number of physical retrofit criteria were developed for both passive and active solar energy systems. It was concluded that it was the interface between the design characteristics of the system types and the construction, placement and orientation of an existing house that ultimately decided the retrofit potential of a solar energy system.

The two case study areas (Sargent Park and Riverview) that have been selected will be evaluated in terms of the physical retrofit criteria identified in Section 3.2. The criteria will be reviewed in the same order as in Section 3.2:

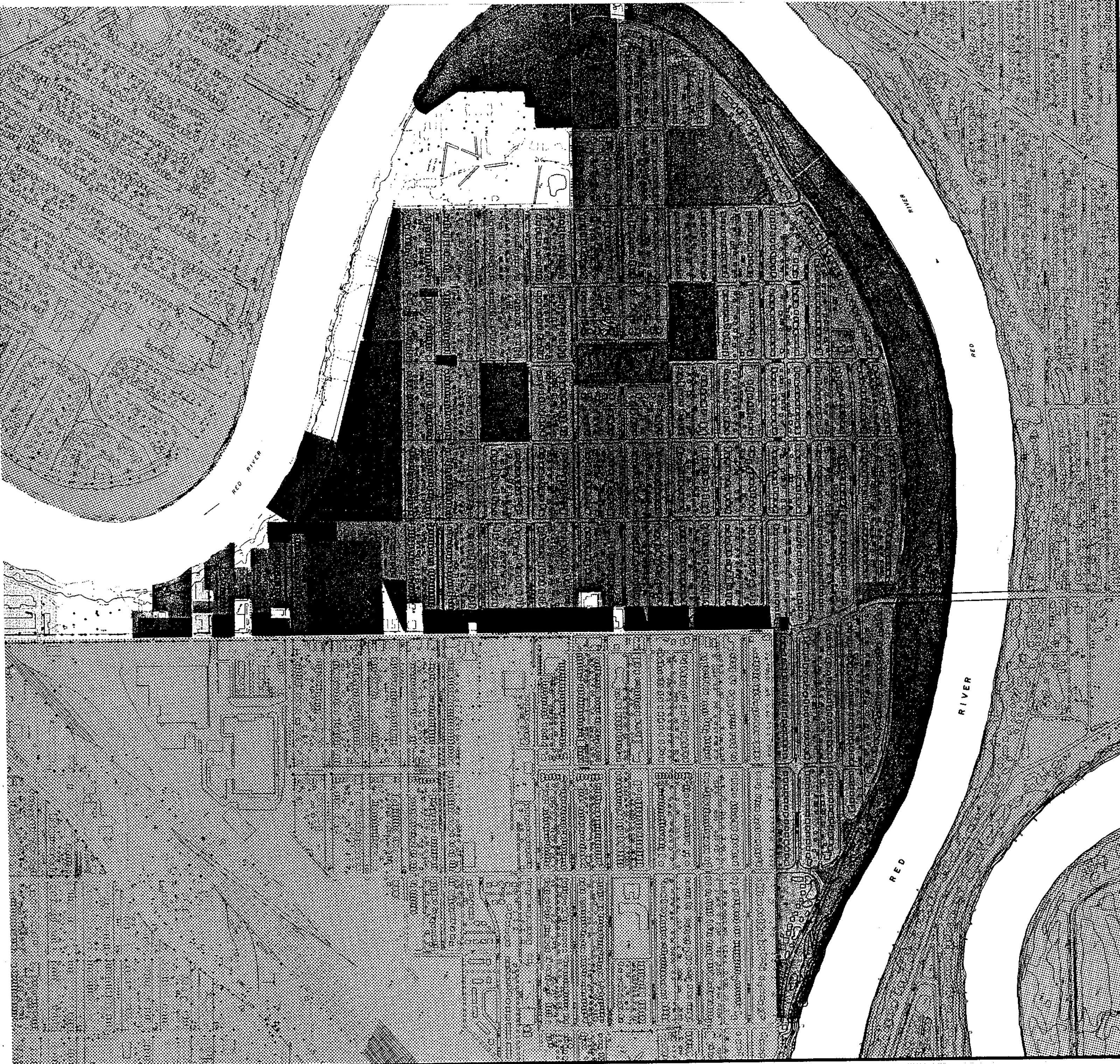
1) Solar Access:
   (a) lot orientation
   (b) solar altitude
   (c) shading by adjacent buildings and/or trees
2) Roof Form/Angle
3) Heat Storage
4) Thermal Insulation
5) Heating System/Fuel Type

1) Solar Access:

(a) Lot Orientation: The retrofit criteria of lot and house orientation was identified in Section 3.2 as critical to the retrofit suitability of both active and passive systems. This criteria was also one of the determining factors in the selection of the two study areas. Sargent Park was chosen as virtually all of the lots in this area are oriented east-west (longitudinal axis) as a function of the predominant north-south orientation of the street layout. Riverview was selected as all of its lots are oriented within 25° east of the north-south axis, and was thus deemed to be an "optimal" orientation for passive and/or active solar retrofit, while Sargent Park would be representative of a "poor" orientation for passive solar retrofit in particular. Initially, this classification of "neighbourhood" retrofit suitability as a predominant function of lot orientation would appear to be true, but other factors such as roof form and solar access can have mitigating effects on overall "neighbourhood" suitability for solar retrofit.

Figure 22 illustrates the land use pattern and lot/house orientation of the Riverview area. Lots in this area are oriented approximately 20 to 25° east of south, which was identified as a close to optimal orientation in Chapter II for passive and/or active systems. Houses with their front or back face (sides normally having the largest percentage of window area) to the east of south, collect solar energy earlier in the morning while minimizing summer overheating in the afternoon. Summer overheating occurs if the primary window faces are oriented to the west of south and major glass collection surfaces are not shaded. While due south is the optimal orientation for active collectors, there is little decline in solar radiation collection within ±30° of south. As can be seen in Figure 22, Riverview is predominantly low-density single family housing, with some multiple-family housing along the east side of Osborne Street. This distribution of land use should allow for uninterrupted solar access for most south-facing wall surfaces in Riverview.

Figure 23 illustrates the land use pattern and lot/house orientation of the Sargent Park area. Lots in this area are oriented east-west, with the primary window faces (front or back) of the houses facing either due west or east. There are a small percentage of lots which are oriented south in Sargent Park, such as located on bays off Clifton Street and Valour Road in the western half of the area - but these lots represent less than 5% of all lots in Sargent Park. The predominant



RIVERVIEW

LAND USE

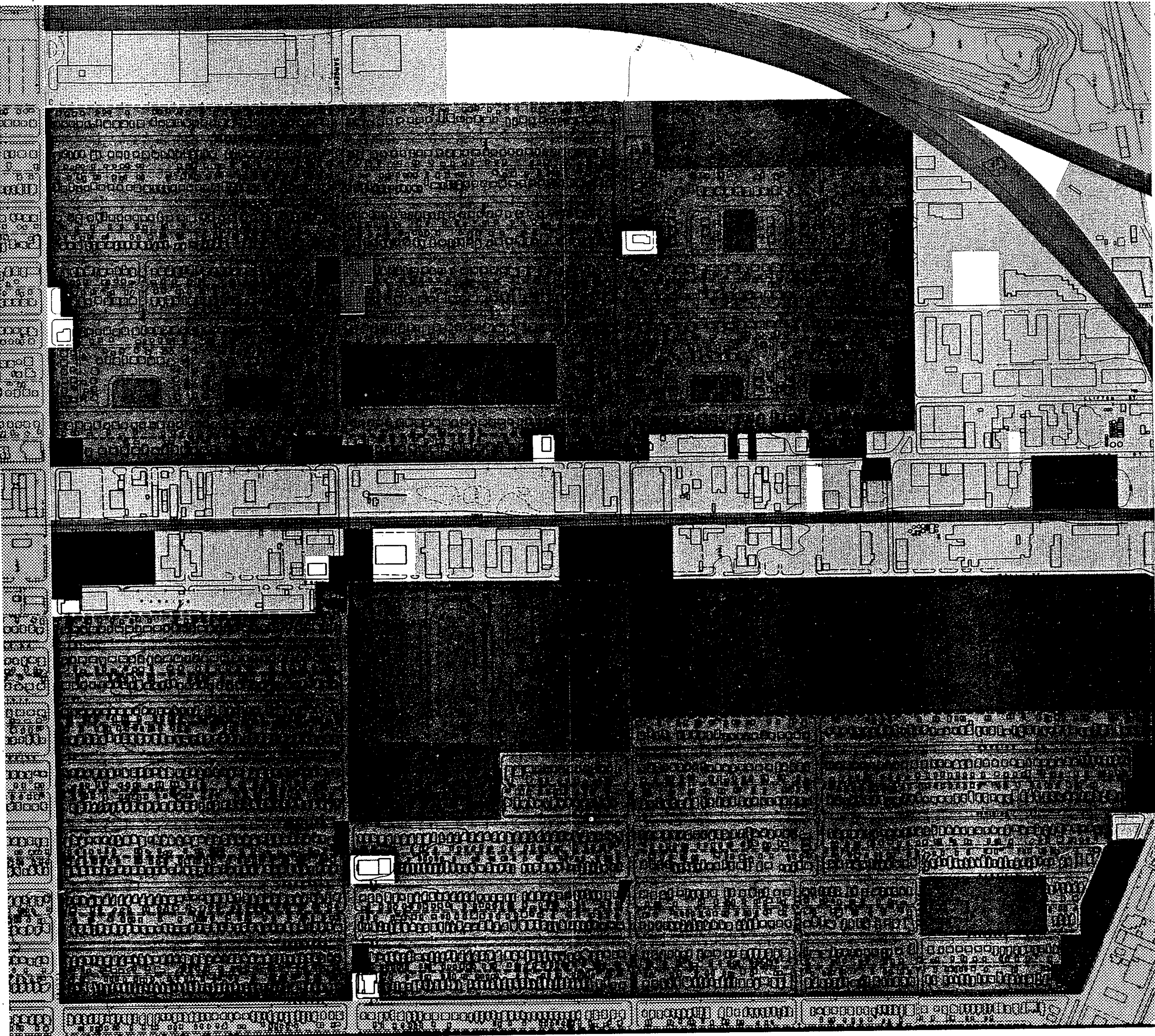
- LOW DENSITY DWELLINGS
- MULTIPLE DWELLINGS
- COMMERCIAL
- PARKS & RECREATION
- SCHOOLS
- PUBLIC BUILDINGS
- INDUSTRIAL
- PUBLIC UTILITIES
- AGRICULTURAL
- VACANT LAND

25°
N

FIGURE 22

THE CITY OF WINNIPEG
DEPARTMENT OF
ENVIRONMENTAL PLANNING

FEBRUARY 1978



SARGENT PARK

LAND USE

LOW DENSITY DWELLINGS

MULTIPLE DWELLINGS

COMMERCIAL

PARKS & RECREATION

SCHOOLS

PUBLIC BUILDINGS

INDUSTRIAL

PUBLIC UTILITIES

VACANT LAND

N

FIGURE 23

THE CITY OF WINNIPEG
DEPARTMENT OF
ENVIRONMENTAL PLANNING

JUNE 1980

east-west orientation of houses in this area is poor from the point of view of passive solar collection, with minimal opportunities for passive solar retrofit. The Sargent Park area is characterized by narrow lots with minimal separation distances between houses, and by shaded south wall faces with few or no windows due to sideyard and separation distance restrictions. In terms of active solar retrofit, again the east-west orientation of primary window faces minimizes the amount of solar radiation that can be collected by the wall surfaces; however, roof form in this area does allow some active solar collection due to south-facing roof surfaces. This factor will be later examined in the section on roof form (one of the five retrofit criteria previously identified).

b) Solar Altitude: This factor will be combined with (c) shading to determine "solar envelopes" or shadow patterns for both study areas.

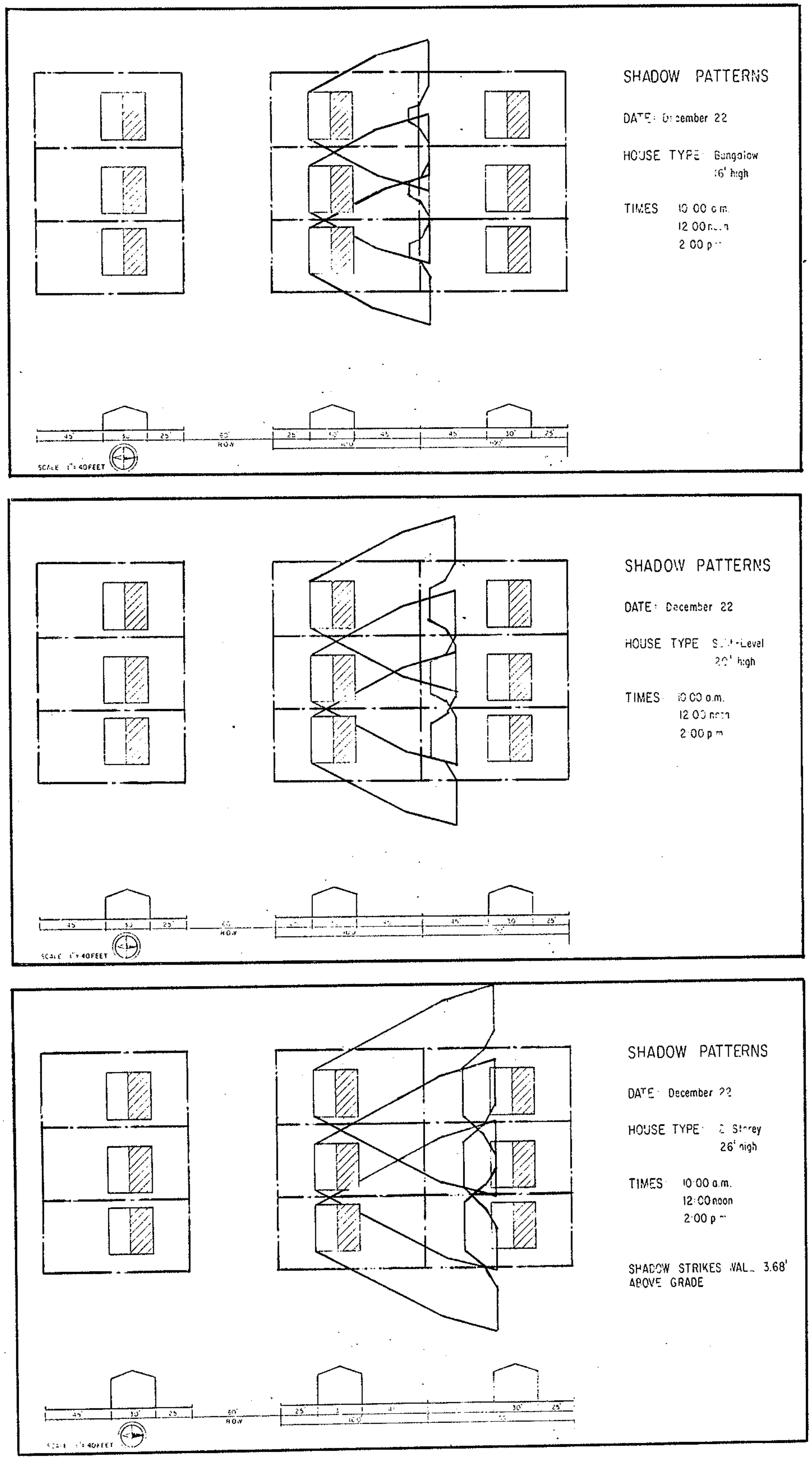
c) Shading by Adjacent Buildings and/or Trees: A key factor in both study areas is the possible shading of south-facing surfaces by adjacent buildings during the winter heating season, particularly at the winter solstice (December 22nd). In order to determine the extent to which this shading occurs and its positive or negative effects upon south-facing collector surfaces, a "solar envelope" can be determined. This "solar envelope" is a function of latitude and solar altitude and specifies a three-dimensional space in which solar collection devices should not intrude, if solar access is to be guaranteed to a house utilizing a solar energy system.

Typically, these shadow patterns developed for winter solar access have been used to determine minimum separation distances in new subdivisions incorporating passive solar design. However, in existing neighbourhoods such as Riverview and Sargent Park, there is a given situation of lot and house orientation and placement. In this case, optimal shadow patterns can be applied to the existing situation, to determine the retrofit suitability at the "neighbourhood" level as a function of solar access.

Figure 24 illustrates the shadow patterns developed for Winnipeg for three typical house heights (bungalow, split-level, and 2-storey) on December 22, the winter solstice. The higher the house (measured at the roof peak), the longer the shadow pattern - thus increasing the minimum separation distance between houses in order to guarantee winter solar access. The lot size used in these shadow pattern examples is a typical 50 feet wide by 100 feet deep. Lots in Sargent Park and Riverview vary from 30 feet by 90 feet to 50 by 100 feet or greater, and in addition there is some mix of house heights, particularly in Riverview.

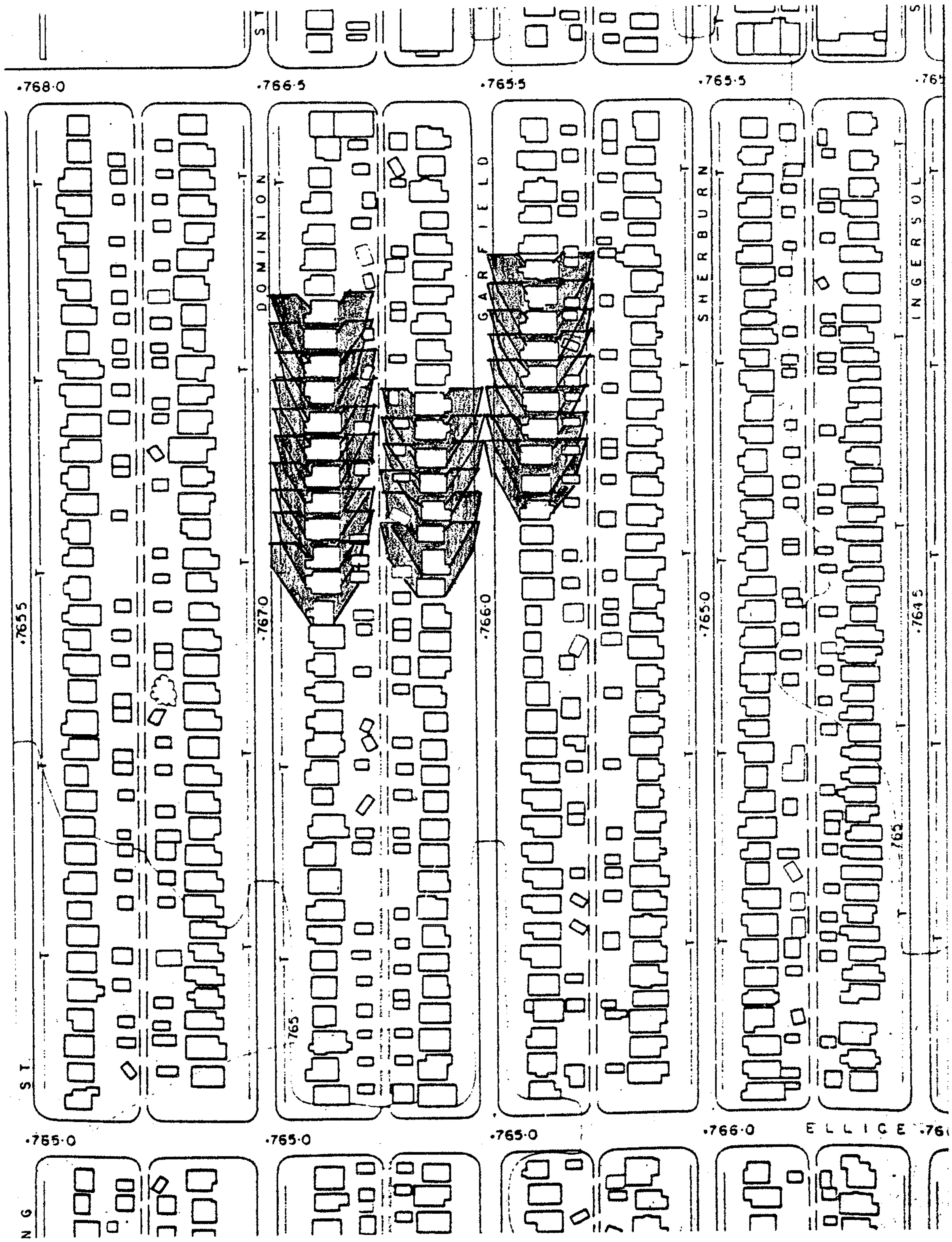
The December 22nd shadow pattern for 49°N. latitude can then be applied to the two study areas to determine to what extent shading by adjacent houses interferes with solar access. The shadow pattern for a single-storey 16' high bungalow was used for Sargent park as this is the predominant housing type, while the shadow pattern for a split-level 20' high house was used for Riverview as this was more representative of the average house height in the area.

It can be seen that when the shadow pattern is applied to a representative four block area in Sargent Park (Figure 25), that south-facing walls have no solar access during the winter heating season, ruling out



Source: I. Torry, Department of Environmental Planning, City of Winnipeg.

FIGURE 24: SHADOW PATTERNS VS. HOUSE HEIGHT AT WINTER SOLSTICE



SARGENT PARK

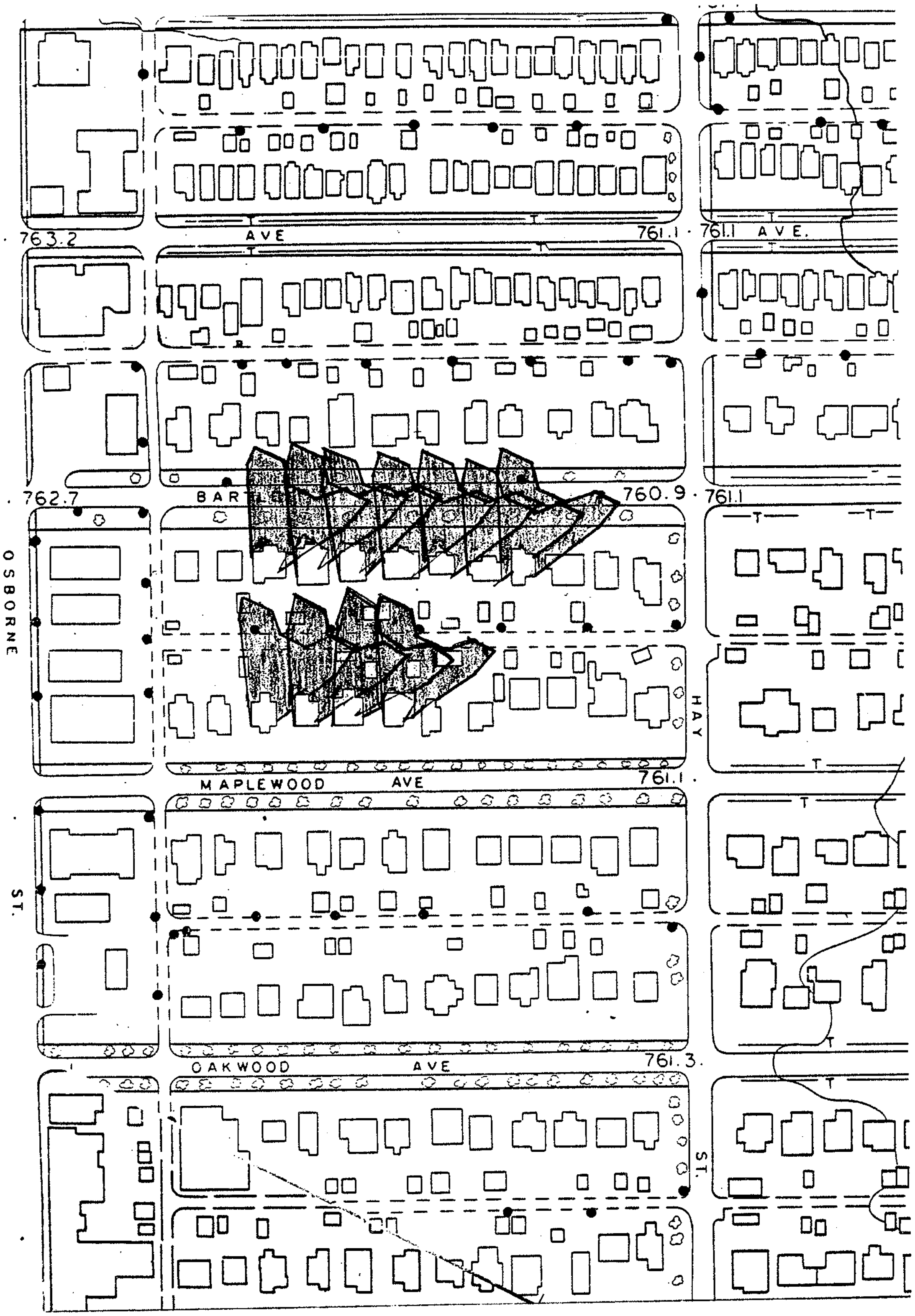
FIGURE 25: SHADOW PATTERNS AT WINTER SOLSTICE

1"=200' N

passive solar collection or wall-mounted active collectors. In addition, free-standing solar collector furnaces in front or rear yards are also largely ruled out due to winter shading patterns.

Figure 26 also applies the 49°N. latitude shadow pattern for Riverview in a 5 block representative area. It can be seen that in this case, due to the favourable lot/house orientation (20°E. of south) there is little or no shading of adjacent south-facing wall surfaces, thus allowing solar access for passive or active solar energy systems. While the lot/house orientation in Sargent Park would limit active solar collection to south-facing, non-shaded roof surfaces, the orientation in Riverview permits wall or roof-mounted active systems (given the correct roof orientation) <u>and</u> passive collection systems integrated in south-facing walls, eg. greenhouses or window walls.

In Section 3.2.1, Figure 18 illustrated the potential shading effects of trees as a function of height and species. Both Riverview and Sargent Park, being existing built-up areas, are characterized by mature street trees, predominantly elm and maple, with the occasional ornamental coniferous tree. These deciduous trees provide desired summer shading to prevent overheating, while losing their leaves during the winter heating season and allowing solar penetration into living spaces, and winter solar access for active or passive solar systems. The extent of winter shading by tree branch patterns should be measured on an individual basis, and this can be checked through the use of a pyranometer which measures solar radiation incident upon a potential collector surface, in order to determine the future efficiency of a solar energy system. While the winter shading by trees appears to be a



RIVERVIEW

FIGURE 26: SHADOW PATTERNS AT WINTER SOLSTICE 1" = 200'

minor factor in both Riverview and Sargent Park, in individual cases this factor may be enough to reduce the collection efficiency of a solar energy system to a marginal or cost-ineffective status.

2) Roof Form/Angle:

As discussed in the previous section on solar access, roof form has an effect on the potential for retrofit of a solar energy system. Figure 27 illustrates the relationship between roof surface orientation and lot orientation for Sargent Park and Riverview, and how this affects retrofit potential for roof-mounted active solar collectors.

In Sargent Park, where 95% of the lots are oriented east-west (longitudinal axis), approximately 75% of the houses are of the simple gable-roof type with half of the roof surface oriented due south. This condition is ideal for roof-mounted active solar collectors for hot water heating, and for space heating if sufficient roof area is available. For example, 250 square feet of collector area (1:4 ratio) is required to provide 40 to 60% of the space heating demand. Other orientations of roof surfaces in Sargent Park result in no south-facing areas available for collectors, thereby eliminating any active or passive solar retrofit potential.

In Riverview, virtually 100% of the lots are oriented within 25° east of the north-south axis. There is a wider range of roof forms and roof surface orientations than in Sargent Park. Approximately 75% of the houses in Riverview have gable-type roofs with one major surface facing south, thus allowing roof-mounted active water and/or space heating collectors. Other roof types with no south-facing surfaces

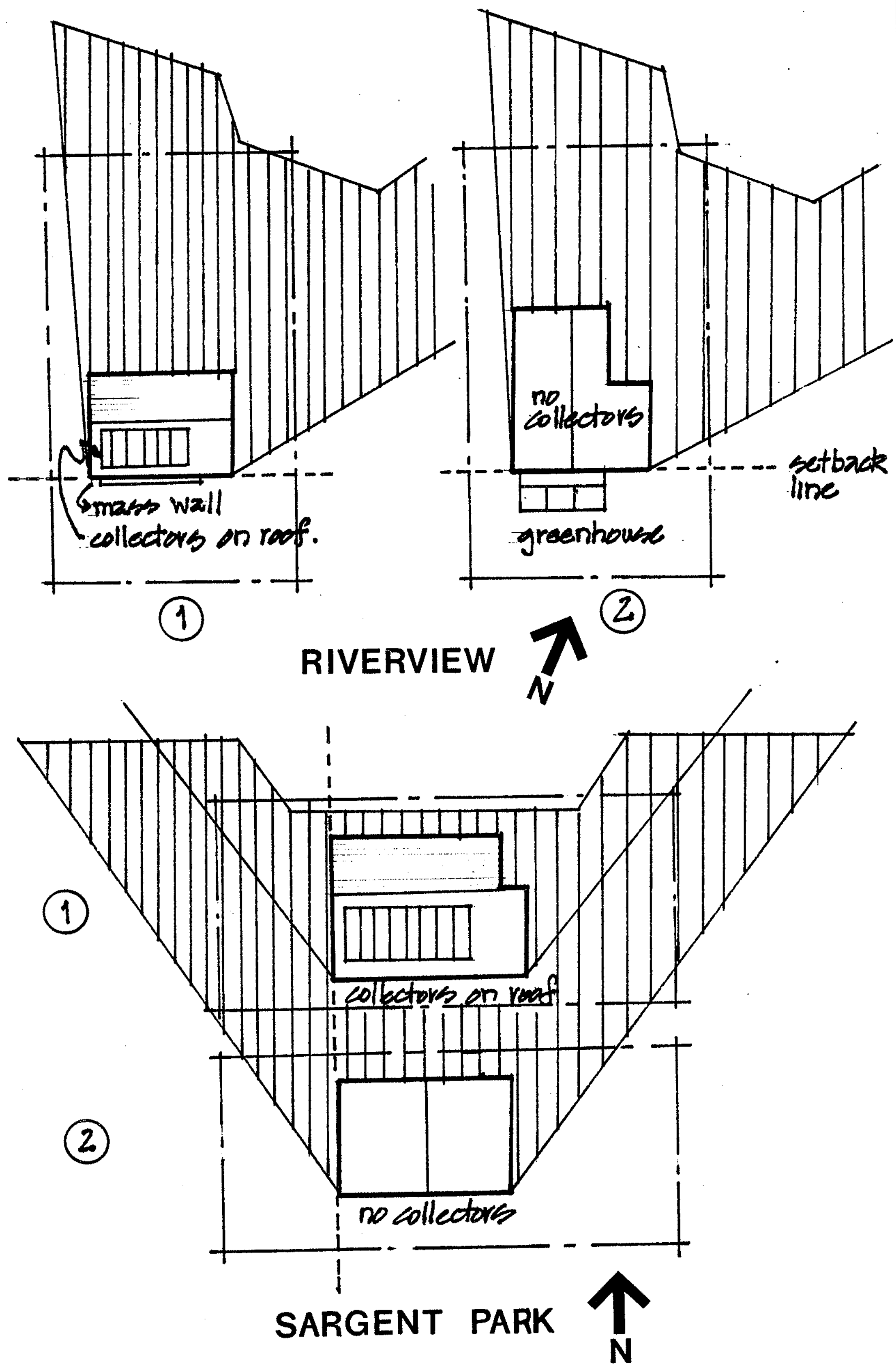


FIGURE 27: POTENTIAL FOR SOLAR COLLECTION: ROOF FORM VS. ORIENTATION

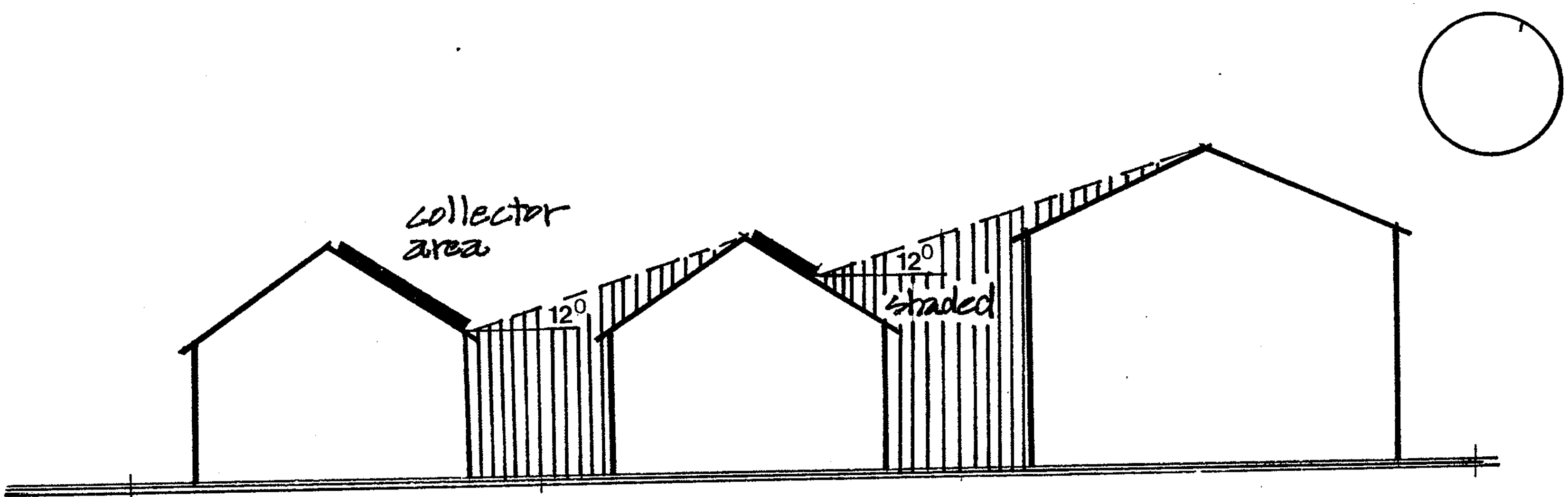
would result in Riverview houses only able to utilize active wall-mounted collectors, passive wall systems, or potentially solar furnaces located in yards having solar access.

One additional factor that is characteristic only to Sargent Park is that south-facing roof surfaces may be shaded by an adjacent house whose roof peak is higher. Figure 28 illustrates the effect of roof height on shading patterns between adjacent units. Where a 2-storey house is located beside a 1-storey house, partial or complete shading of south-facing roof surfaces will occur. This additional factor decreases the percentage of Sargent Park houses having roof surfaces suitable for active collectors from 75% to approximately 60% of all houses.

Prior to the consideration of <u>any</u> solar collector installation, an analysis should be carried out to determine the area of south-facing roof surfaces that are shade-free at the winter solstice, and whether this area is sufficient for space heating or water heating purposes only. As previously mentioned, the potential shading effect of street trees on solar collector surfaces should be also be taken into account.

3) <u>Heat Storage</u>:

It is difficult to estimate to what degree heat storage volume would be a limiting factor in the two case study areas of Riverview and Sargent Park. Visits to houses in both of these areas reveal that most people have undertaken complete finishing of their basements, thus limiting the amount of space available for large insulated water tanks or rock beds for active space heating systems - unless they are placed adjacent to the house, either underground or in insulated beds. Storage



ROOFTOP SOLAR ACCESS

FIGURE 28: ROOF HEIGHT AND SHADING EFFECTS

volume for hot water domestic heating would present few problems in terms of space, while eutectic salt storage (in trays) is the most space-efficient means of heat storage for active air systems, at a slight premium in operational costs. However, the most space-efficient and convenient means of heat storage may not be compatible with the existing means of heat distribution - i.e. an active air system employing eutectic salt storage would not be compatible for a house with existing radiant water heating. This additional factor will be examined in a further section on existing heating systems and fuel types.

In terms of passive heat storage, it appears that there would be little opportunity to capitalize on existing masonry construction as a means of heat storage for a mass wall system, as existing construction in both Riverview and Sargent Park is predominantly wood-frame. A "windshield survey" of these two areas indicates there is a higher percentage of existing masonry construction in Riverview than in Sargent Park, but that probably does not represent more than 5 to 10% of existing housing in this area. As noted in Chapter II, the existence of masonry construction (brick or stone) as a means of passive thermal storage may still not be adequate, if these masonry walls are not of adequate thickness, construction type (i.e. cavity wall) or are not south-facing walls. It is important to assess the potential of this type of passive heat storage on a case-by-case basis. However, this does not eliminate the possibility of constructing a new masonry wall or water tube wall adjacent to an existing wood-frame wall (that is well insulated) if one wishes to use this type of passive heating system to heat as adjacent living space.

4) Thermal Insulation:

As outlined in Section 3.2.1, the sizing of a solar energy collection system for an existing house will be dependent on the house's present thermal efficiency. The greater the level of energy consumption for space heating, i.e. the more thermally inefficient the house is, the greater the collector area and thermal storage volume required for a solar system. The design and construction of a house to be retrofitted may place limits on the usable collector available and sufficient storage volume available (i.e. a storage container in the basement). Due to these limitations, the solar energy system will provide a lower fraction of the total heat demand and will certainly be less cost-effective. Thus, greater importance should be placed on the thermal upgrading of existing "neighbourhoods" prior to any consideration of solar energy collection. For an existing house, thermal upgrading is the most cost-effective first investment, and would include such items as reduction in air infiltration, attic and wall insulation addition, triple-glazed windows, etc.[9]

While housing age is not directly correlated with thermal efficiency, it is an indicator of insulation levels as a function of changes in the National Building Code and construction practices at the time of house construction. Table 16 illustrates the distribution by age for Sargent Park and Riverview up to 1971, indicating that for both these neighbourhoods approximately 97% of the housing was built prior to 1960 and that both neighbourhoods are older than the city average.

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9 See Ajmal Mohammed's thesis Conservation of Energy in Housing, University of Manitoba, 1980.

Table 16: Period of Construction

Period	Sargent Park No.	Sargent Park %	Riverview No.	Riverview %	City %
Before 1920	255	11.2	415	23.3	20.1
1921 - 1945	1075	47.4	465	26.1	21.4
1945 - 1950	450	19.8	400	22.5	11.2
1951 - 1960	400	17.6	455	25.6	22.0
1961 - 1965	45	1.9	40	2.2	11.7
1966 - 1971	40	1.6	-	-	13.2
TOTAL	2265	100.0	1775	100.0	100.0

Source: Department of Environmental Planning, City of Winnipeg (Statistics Canada).

In 1979, Scanada Consultants completed a study for the Canada Mortgage and Housing Corporation on insulation levels in existing housing across Canada, and arrived at the following average levels of insulation ("R" value) and percentage distribution as a function of period of construction for Winnipeg, as shown in Table 17.

Table 17: Wall and Attic Insulation Levels and Occurrence (Winnipeg)

Period of Construction	Wall Insulation "R" Value	Wall Insulation %	Attic Insulation "R" Value	Attic Insulation %
Before 1945 (UN)	4.3	26	3.1	8
(IN)	9.8	74	12.6	92
1945 - 1950 (UN)	4.3	10	-	-
(IN)	8.0	92	13.1	100
1950 - 1960	10.0	100	13.1	100
1960 - 1975	10.0	100	14.2	100
After 1975	13.5	100	14.2	100

(UN): Uninsulated (IN): Insulated

"R" Values are in (Btu/hr.ft.^{2} °F.)$^{-1}$. Estimated values are based on ENERSAVE (CMHC).

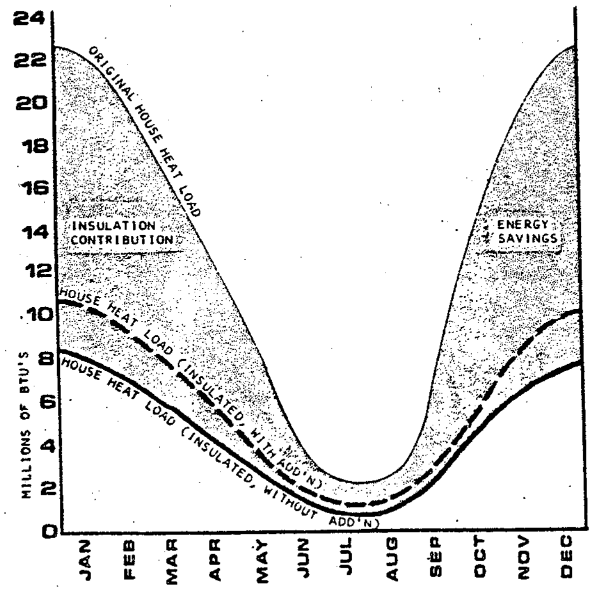
Source: Derived from tables in Heating Canadian Houses: Current Performance and Potential for Improvement, (CMHC, Policy Development Division, by Scanada Consultants, Ottawa, March 1979), pps. 34 & 35.

As 78.4% of the housing in Sargent Park and 71.9% of the housing in Riverview was built prior to 1950, it appears that much useful thermal upgrading of insulation would be necessary prior to any consideration of solar energy collection systems. Figure 29 indicates the dramatic effect of the energy savings due to additional insulation contribution (Graph 1), and the subsequent contribution that can be made by a solar space-heating system (45% solar fraction) to the thermally upgraded house.

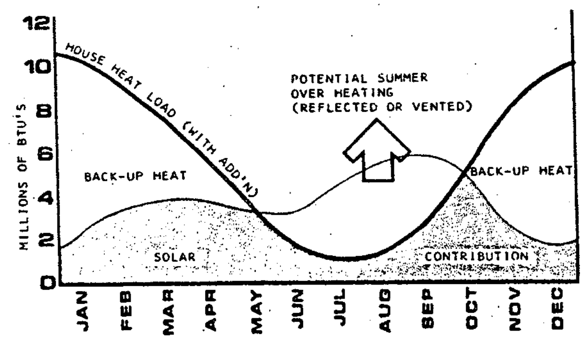
A detailed, area-specific insulation level study could be conducted for both Sargent Park and Riverview through the use of aerial thermograms, revealing the present level of attic heat loss (as a function of insulation levels and air infiltration). Appendix A-1 outlines such a program in Toronto. This type of study could then further identify those houses most suitable for solar energy retrofit as a function of lowest relative heat loss in the case study areas, given that other conditions such as solar access and cost-efficiency have been met. It is recognized, however, that this method of aerial thermograms only identifies roof heat loss, and not wall heat loss or the existing level of air infiltration in a house - two other problem areas that should be resolved prior to evaluating the retrofit of a solar energy system.

5) Existing Heating System and Fuel Type:

As previously noted, the existing type of heat distribution and fuel market penetration for an area will influence both the physical and economic suitability of a solar energy collection system for retrofit purposes. Table 18 indicates the present distribution of heating system



GRAPH 1



GRAPH 2

Using the worksheets and data to be found in SOLPLAN 2, an analysis was carried out for the example house. The results of the work to be done on the house are summarized in Graphs 1 and 2. Insulation is by far the best possible investment to cut heating bills.

Graph 2 shows the solar contribution to the reduced heat load of the house. Our calculations show that the sun should contribute about 45% of annual heating requirement. As this work is being undertaken as part of a major building program, without a major investment in expensive solar hardware, its cost effectiveness is easy to see.

Source: Solplan 2: Solar Energy for Existing Homes, R. Kadulski, et al., (Drawing-Room Graphic Services Ltd., Vancouver, B.C., July 1978), P. 30.

FIGURE 29: INSULATION AND SOLAR CONTRIBUTION TO HOUSE HEAT LOAD

Table 18: Heating Equipment Distribution and Fuel Type (Winnipeg)

	% Utilizing Space Heating	% Utilizing Water Heating
DISTRIBUTION TYPE		
Hydronic (water radiant)	6.0	
Forced Air	76.0	
Electric Radiant	13.0	
Other	5.0	
	100.0	
FUEL TYPE		
Natural Gas	84.0	84.0
Electricity	13.0	16.0 (mostly electricity)
Oil	8.0	
Other (Coal, Wood, etc.)	1.0	
	100.0	100.0

Source: Household Facilities and Equipment, Statistics Canada, Ottawa, May 1978.

types and fuel used for Winnipeg, values for which both Riverview and Sargent Park should be close to as they were selected as areas "representive" of Winnipeg. Both Sargent Park and Riverview areas are 100% served by natural gas utility lines, but actual natural gas market penetration in these areas is estimated to be 85 to 90% (slightly higher than the Winnipeg average) with the remaining share of the market served by electricity and oil.[10] In some cases, houses in these areas may have two different fuel sources for space and water heating, i.e. natural gas for spacing heating and electricity for water heating, but data for this type of distribution was not available. Generally, the primary fuel chosen for space heating purposes will also be used for water heating purposes.

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10 Source (Fuel Type): Mr. W. Salo, Winnipeg Gas Company, Winnipeg, 1981.

Distribution of heating equipment and fuel type may also vary with housing age (period of construction), but this data was not available for the two study areas and might be obtained by specific surveys. Table 18 does indicate, however, that the predominant type of space heating in Winnipeg and the 2 study areas is natural gas, using a forced air distribution system (approximately 85%). Thus, the largest space-heating potential for solar retrofit is the Sargent Park and Riverview areas would be for active air systems, most likely with space-efficient eutectic salt storage. This does not rule out, however, the use of liquid-based solar collection systems as a water-air heat exchange element can be used to preheat furnace air intake, in order to be compatible with an existing forced air heat distribution system. The predominant market penetration in Winnipeg of natural gas for both space and water heating will most likely act as a deterrent to wide-scale implementation of solar space heating systems, as natural gas currently has a price advantage over competing fuels.

3.5 MECHANISMS TO PROTECT SOLAR ACCESS

Other than cost-effectiveness, it can be seen that the lot/house orientation and solar access are the prime determinants of retrofit suitability for both active and passive systems. There are a number of legal and technical means of accomplishing the objective of protecting solar access:

1) Solar overlay zoning

2) Restrictive Covenants

3) Private Agreements and Solar Rights

4) Zoning by-law variances and Site Certifications.

Each of these mechanisms will be defined and discussed in terms of their effectiveness in protecting solar access in existing urban areas.

1) Solar Overlay Zoning:

Solar overlay zones can be used to protect solar access for both new and existing housing. Municipalities can define "solar zones" for specific areas in which existing solar access is already beneficial, so that future building construction will not shade solar collection surfaces. Solar zones are overlaid on existing residential zoning categories, such as single-family "R1", accompanied by varied degrees of protection. One of the means of implementing solar zoning is through the control of building permits for new construction in existing neighbourhoods, by regulating building heights and spacing in order to minimize shading on potential solar collection surfaces. Depending on the retrofit potential of an urban area, as determined through case studies such as in Section 3.4, various degrees of protection can be implemented by total or partial exemptions from existing zoning restrictions.[11] Restrictions which might or might not be granted could include yard setbacks, building height, vegetation height control, or lot coverage.

For existing areas such as Riverview, with good existing solar access for south-facing wall and roof surface, and with little external

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11 Perspectives on Access to Sunlight, Ontario Ministry of Energy, Toronto, September 1980, p. 32.

development pressure, the majority of the area could be classified as a high-priority "solar zone." Problems that could be incurred by such a mechanism would be the degree of protection granted - should the solar zone protect access to all south-facing wall surfaces (or a fixed percentage of), or for roof surfaces only, and should exemptions be granted for the construction of accessory structures such as garages? It is also unlikely that this concept of solar zoning could be applied to vegetation height control, particularly in an area with mature street trees that provide beneficial summer shading. Solar zoning with accompanying building permit restrictions would most likely be confined to physical structures and apply only to future construction, i.e. it could not be retroactive in its application.

For existing areas such as Sargent Park, which has minimal opportunity for protecting solar access, limited forms of "solar zoning" could be applied to protect only roof surfaces for domestic hot water heating (small collection areas). This would not protect roof areas currently shaded by adjacent taller houses, and might also prevent second-storey additions to existing houses. "Solar zones" may not be able to be applied to all areas of the city due to existing physical restrictions, and thus other mechanisms such as private agreements or restrictive covenants may be more appropriate to protect solar access where future potential for solar heating is limited. For other urban areas, a hierarchy of solar zones could be defined with decreasing levels of solar access proection, as a function of existing "neighbourhood" physical characteristics. Areas such as Riverview could have a maximum level of controls, while areas such as Sargent Park with poor solar access, or areas subject to development pressure from expanding commercial districts, would have a minimum level of controls or no controls.

2) Restrictive Covenants:

Covenants are agreements between individual property owners and do not affect future owners of the property (i.e. are not binding on the title to the land), unless they take the form of "restrictive covenants."[12] Restrictive covenants can be used to protect solar access to a collector, by preventing construction of buildings or additions above a specified height, or by stipulating the retention of deciduous trees for summer shading or the removal or trimming of coniferous trees shading collection surfaces. This type of mechanism can be more easily acquired in new subdivisions which have been optimally designed for passive solar collection, but may have only limited applicability for existing neighbourhoods - particularly with regard to enforcement. Such agreements may also be limited only to future building construction, and not to existing or future vegetation growth. The property owner (or owners) "restricted" in such a fashion may also warrant compensation for loss of development potential or privacy screening of property.

As restrictive covenants are carried with the title to the land, and may be difficult to acquire and to enforce, it appears that they have limited applicability to existing neighbourhoods. However, if no other mechanisms to protect solar access are available (such as "solar

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12 Ibid., p. 6.

zoning") then restrictive covenants may be the only way to accomplish this objective. Implementation of restrictive covenants also becomes increasingly difficult for existing areas having less than optimal solar access, and for areas under redevelopment pressure from adjacent land uses.

3) Private Agreements and Solar Rights:

Private agreements between affected property owners are a form of covenant, but are not registerable against the title to land. A contract can be agreed upon between neighbours restricting future building or vegetation, but it only binds the people that sign the agreement and will not protect future property owners. In existing areas with high turnover rates (length of ownership) this type of agreement would have to be re-negotiated with new owners, thus decreasing the "permanance" of such an agreement.

All of the previous conditions applying to the use of restrictive covenants in existing areas will also apply to private agreements - the only difference being the legally enforceable status of a restrictive covenant. The use of private "solar rights" would require authorized legislation, and this already has been accomplished in several U.S. states.[13] There are several advantages to the use of solar rights by private agreement:[14]

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13 Ibid., p. 14 & 77. The State of Colorado in 1975, and the States of Kansas, Maryland and North Dakota in 1977 gave legislative sanction to private agreements for "solar rights."

14 Ibid., p. 16.

(a) Solar rights can be obtained from adjacent affected property owners prior to the purchaser installing a collector.

(b) The content of a private agreement for solar rights can be as extensive or as minimal as the property owners mutually agree to contract.

(c) The solar user, after complete analysis of a solar retrofit installation, can design and size his collector in order to minimize the impact upon adjacent affected property owners.

(d) Solar rights negotiated by private agreement can be sufficiently flexible to accommodate the user's technical and economic requirements, particularly for retrofit installations.

(e) Solar rights could be supplemented by other mechanisms to protect solar access, such as "solar zoning"; or where such mechanisms did not exist this would be the only viable means of protecting solar access.

There are, however, potential disadvantages to the acquiring of solar rights by private agreement. Disadvantages could include: lack of applicability for areas with poor existing solar access, compensation required by affected property owners, lack of transferability to future property owners (unless conveyed by authorizing legislation), and difficulty in enforcement. The use of private agreements, though, does have potential where few owners are involved, where mutual agreements can be made, and where municipal governments have not yet provided any other mechanism to protect solar access.

4) Zoning By-Law Variances and Site Certifications:

Where the use of passive and/or active solar energy collection systems contravene specific regulations such as front yard setback restrictions or height restrictions, the use of variance appeals by municipalities can be implemented. It was determined in the case study in Section 3.4 that in Riverview the front-yard setback restriction (25 feet maximum under "R1" zoning) could effectively reduce the number of houses capable of using certain types of solar collection by 50%. This occurred where houses on the north side of east-west streets were built at the setback line, and use of passive collection systems on south wall faces (such as tube walls or greenhouses) would encroach on the front-yard setback.

Granting of variances for tube or trombe walls, thermosiphon systems, or flat-plate collectors could be easily granted where encroachment on the front-yard setback was only minimal (i.e. two feet). However, the use of attached greenhouses or sunspaces encroaching by as much as ten feet, would most likely be opposed by adjacent property owners at public hearings held for variance appeals. It is difficult to separate the issues of additional "living space" obtained by attached greenhouses and the passive solar energy that could be collected by such an addition. It is likely that municipalities will have to adopt some regulations permitting the use of passive solar greenhouses up to certain specified dimensions, depending on the existing zoning regulations and neighbourhood physical characteristics. For "neighbourhoods" such as Riverview, this particular restriction appears to be a major deterrent for the implementation of certain types of solar energy collection systems, particularly attached sunspaces on south-facing wall surfaces.

In addition, upon the granting of such variances for solar systems municipalities could issue solar "site certification," which could impose solar rights restrictions on adjacent properties that might potentially shade the certified site through future construction. The use of "site certifications" could also be integrated with the property tax assessment system, providing a means of documentation for exemption of the value of a solar energy collection system from additional property taxes.[15] This particular mechanism of protecting solar access and encouraging the adoption of solar energy systems does hold promise for existing areas with good solar access (such as Riverview), but would be difficult to apply in areas with non-optimal orientation.

3.6 CONCLUSIONS AND RECOMMENDATIONS

From the preceding case study of Sargent Park and Riverview, and the identification of retrofit suitability criteria as a function of solar system type and locational requirements, it is possible to estimate the potential for solar retrofit for the two study areas. Each type of solar energy collection system will have factors limiting its ultimate retrofit potential as a function of physical conditions such as roof area, solar access, storage volume, materials, etc.. The physical constraints identified in the case study of Riverview and Sargent Park can be summarized as follows:

Physical Constraints:

1. Lack of solar access as a function of existing lot orientation, roof orientation, and shading by existing roof form, buildings, and trees.

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15 Ibid, p. 50-51.

2. Lack of usable, south-facing collection surfaces (particularly for space-heating) having sufficient area, due to existing roof form and orientation.

3. Loss in solar collector efficiency due to non-optimal existing roof angles, requiring additional installation costs or larger collection areas to obtain the same percentage of solar heat (solar fraction).

4. Insufficient thermal storage volume for active space heating systems due to lack of existing space, or at additional construction costs; lack of existing masonry floor and wall construction for passive thermal storage.

5. Imcompatibility between existing heating systems (mode of distribution) and some types of active solar systems available for water and space heating.

6. Insufficient insulation levels in existing houses resulting in larger collection areas and heat storage volumes in order to provide the solar fraction desired (i.e. 40 to 60%).

7. Existing municipal zoning by-law and code restrictions, particularly with regard to front-yard setback restrictions, thus eliminating or reducing the possibilities for passive and/or active space heating systems on south-facing walls built at the setback line (e.g. Riverview).

8. Aesthetics: Design or visual integration of the collector area, passive or active, into the house and consumer acceptability. Roof-mounted active collectors provide the least problem in terms of visual integration, while wall-mounted active or passive collector areas require careful design consideration of the existing facade (elevational treatment).

Major limiting factors affecting market penetration, such as solar access and roof orientation, were determined for two case study areas. As a result, the two Winnipeg study areas of Riverview and Sargent Park ultimately have different potentials for the retrofit of solar energy systems, as a function of system type and physical characteristics of the study areas.

The retrofit criteria identified in Section 3.2 can then be reviewed in terms of the commonly used active system types (flat-plate water or air, evacuated tube water) and their characteristics (storage, collector areas, distribution system) in order to determine their retrofit potential. Table 19 outlines the percentage of units in the two study areas that might be capable of using the different types of active and passive systems. The percentages derived are estimates based on the number of units that would meet the criteria, for example, of solar access to utilize a solar system efficiently.

From this summary table, it can be seen that Riverview as an area has a greater potential for solar retrofit than Sargent Park, and this tends to support the initial selection of these two areas as "optimal" vs. "poor". Sargent Park has a greatly limited potential to implement any means of passive solar collection due to solar access problems, other than a small percentage of separated thermosiphon systems in rear yards where solar access is available. Contrary to first impressions, Sargent Park does have good potential for active systems (particularly hot water) given favourable roof surface orientations, and does have some potential for active space heating systems if efficient collectors (i.e. evacuated tube) are used due to limitations in usable roof area for solar collection.

Riverview, as initially perceived, has very good potential for both active and passive solar collection. There may be, in some cases, insufficient solar access due to tree shading or shading on wall surfaces by nearby houses or physical objects (fences, garages, etc.). Usable roof area with good orientation may also limit the percentage of units capable of using active systems due to variations in roof form and size. A major problem for passive solar collection in Riverview are

Table 19: Study Area Retrofit Potential: Summary Table

SYSTEM TYPE	% OF UNITS CAPABLE OF USING SYSTEM TYPE: Sargent Park	Riverview	MAJOR LIMITING FACTORS
PASSIVE			
Direct			
1) Window Wall	5%	30%	Existing facade; aesthetics
2) Sunspace	5%	40%	Setback restrictions (front yard); solar access
Indirect			
1) Mass wall: existing masonry	2%	5%	Existing construction
new masonry	5%	50%	Solar access; construction
2) Tube wall		50%	Solar access; construction
3) Thermosiphon: integrated	5%	40%	Solar access; setback restrictions
separated	10%	30%	Solar access; rear yard
ACTIVE			
Flat Plate/Evacuated Tube			
1) Hot Water Heating	60%	80%	Roof form and area
2) Space Heating	30%	70%	Roof form and area; system efficiency
3) Space and Hot Water Heating (Combined)	20%	60%	Roof form and area; system efficiency; thermal storage

front yard setback restrictions limiting the construction of any means of passive solar collection other than a window wall (such as an attached sunspace, mass wall, etc.) intruding into the setback space under existing zoning bylaws. This could be the case for up to 50% of all Riverview houses, where south-facing building walls on one side of a street are built at the front yard setback line (i.e. 25 feet under "R1" zoning). By removing this particular factor as a deterrent to passive solar collection, the percentage of units in Riverview able to use additional types of passive solar collection would be increased.

As a result of these specific physical constraints to the retrofit use of solar energy systems, key policy recommendations can be made to overcome or alleviate the effects of some of these constraints. Table 20 indicates specific policy recommendations, the mechanisms by which they can be accomplished, and the responsibility area involved (i.e. level of government). Technical means to implement "physical" policy recommendations, such as protecting solar access, are almost exclusively the responsibility of municipal governments, other than enabling legislation by provincial governments so that local governments can adopt and enforce new by-laws. Ultimately, the implementation of solar energy systems for existing housing will require the active involvement by individual home-owners, and government policy should recognize this through demonstration and information dissemination programs.

To conclude, some broad recommendations can be made as an outcome of this study that will encourage the solar retrofit of existing housing:

1) Thermal upgrading of existing housing should be brought up to

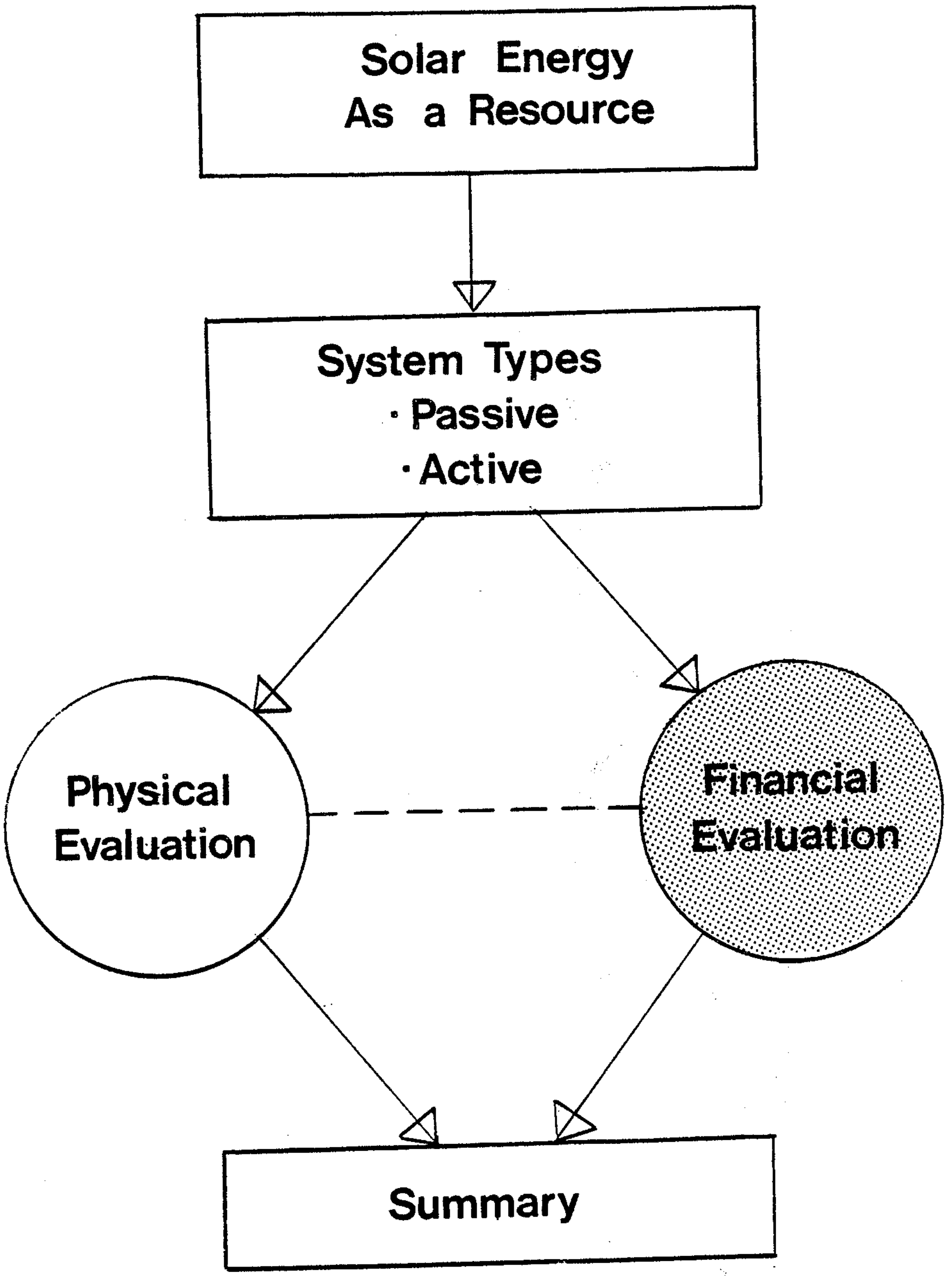
Table 20: Policy Recommendations for Physical Retrofit

POLICY	MECHANISMS	RESPONSIBILITY AREA			
		Municipal Government	Provincial Government	Federal Government	Other
Physical					
1. Protect future solar access to south-facing surfaces	. solar overlay zoning	X			
	. building code restrictions (heights, building permits)	X			
	. restrictive covenants or easements	X			Individual Owners
	. private agreements				"
	. enabling legislation (solar rights)		X		
2. Allow certain types of passive and/or active systems to encroach on the front yard setback	. by-laws	X			
	. variance granting	X			
3. Thermal upgrading of existing houses (insulation levels, air infiltration)	. financial and technical support; survey of existing conditions	X	X	X (ie. CHIP)	Individual Owner

new housing standards (or some other specified standard), before a solar retrofit installation should be considered.

2) The most effective mechanisms of protecting solar access for existing neighbourhoods should be given enabling legislation and municipal adoption - in particular the use of solar overlay zoning, solar rights acquired by private agreements, and the adoption of zoning by-law variances and solar site certification.

CHAPTER 4: FINANCIAL EVALUATION OF SOLAR ENERGY SYSTEMS



STRUCTURE

4.1 CRITERIA FOR FINANCIAL EVALUATION

The cost of solar energy systems is still generally perceived as a barrier to their implementation, due to the high initial capital costs required and resistance by consumers to incur these costs. However, there may be a consumer preference for solar energy for space and water heating purposes due to potential lower life-cycle costs versus conventional energy sources of oil, natural gas, and hydro-electricity.

When evaluating the financial benefits of a solar energy system there are essentially two methods of evaluating cost. The first is "payback period", which is defined as "the number of years required for the cumulative net revenues (fuel savings) to equal the original capital investment".[1] The second method of evaluation is "life cycle cost", which is "the total amount of money which must be budgeted for at the start of the first year of operation to cover the initial capital cost and all the operating costs over the useful life of the system".[2]

Life-cycle costing is essentially a more accurate method of comparing alternative solar energy systems, as it takes into account more fully the stream of revenues and expenditures on an annual basis over the economic lives (i.e. beyond the payback period) of the systems. The values obtained for life cycle costs, however, are highly dependent on the economic assumptions made concerning such factors as real fuel

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1 Turn on the Sun, (Ontario Ministry of Energy, Toronto, September 1977), p. 15.

2 Ibid., p. 15. Both methods will be explained in more detail in Sections 4.2 and 4.3.

escalation rates and user discount rates (mortgage or alternative investment rate).[3]

Solar energy systems for solar pool heating, domestic hot water and space heating can be competitive on a life-cycle basis, but this is dependent on a number of factors - including the type and size of system chosen, its geographic location, its collector efficiency, the length of term and mortgage rate set for repayment, operating costs, government subsidies, exemption from property tax assessment, and the cost of the conventional fuel that the solar system replaces (other than the back-up system) during the repayment term. Energy use is often constrained by capital investments in fixed equipment, i.e. an electric hot water heater, and therefore the short-term demand for alternative heating fuels has been relatively inelastic. Once an investment is made for residential heating equipment, it would take a great increase in the price of the conventional fuel (oil, gas or hydro) before it would be worthwhile to replace the existing equipment and fuel as a backup source.

To summarize, the following factors should be taken into account when evaluating the cost-benefit aspects of adapting a solar energy system (active or passive) to a house:

1) The system type used (water and/or space heating).

2) The solar fraction supplied by the system (% of current energy requirements met by the solar system), a function of the system type, collector efficiency, and the regional and annual variability of solar insolation.

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3 The current mortgage rate is usually set as the user's discount rate to calculate the "present value" costs and savings of a solar energy system.

3) The type and cost of the conventional fuel replaced by the solar system (partial substitutes).

4) The projected real rate of cost escalation for the conventional fuel replaced.

5) The downpayment and mortgage rate used if money is borrowed to finance capital costs of a solar system.

6) The length of the loan repayment term versus the projected length of ownership for the dwelling in which the solar system will be installed.

7) The inclusion or non-inclusion of the market value of the solar system to be installed in the local property tax system.

8) Government grants available to reduce initial capital outlay.

9) Deductibility of capital and/or operating costs of the solar system through the personal income tax schedule, including capital cost allowance (depreciation).

10) The existing dwelling construction and its effect, negative or positive, on installation and materials costs (capital outlay).

Inclusion or non-inclusion of these factors, and assumptions about their future values, will affect the life-cycle cost total and the length of the payback period (balance between negative cash flow in the early years and positive cash flow in the later years). By determining which of these factors (i.e. mortgage rate, initial cost, inclusion of value in property tax assessment) have the most effect on reducing life-cycle costs, policy recommendations can be made so that cost becomes less of a constraint to the use of a solar energy system.

Variables such as government grants, preferred loan rates, fuel escalation rates, system capital costs, and net fuel savings will ultimately affect the market penetration rate of a particular solar system type in a particular area. To summarize, the issue of cost as an argument for implementing solar energy systems has both positive and negative aspects, dependent on the factors mentioned above.

4.2 PAYBACK PERIOD

The simpler method used in examining alternative investments in solar systems is the payback period, which has been defined as "the number of years required for the cumulative net revenues (fuel savings) to equal the original capital investment."[4] In comparing a given heating system with another which has a lower initial capital cost but higher operating costs, the reduction in operating costs is regarded as revenue and the incremental capital cost is regarded as the capital investment. The length of the payback period will be affected by such factors as the modifications required to an existing dwelling to install a solar system, or the type of fuel presently used. A major disincentive for most solar energy systems is that investors usually place a high premium on early recovery of capital, i.e. a payback period of five years or less. Thus, a home owner may not choose the system having lower cumulative life cycle costs, if the payback period on any incremental initial investment is too long. This usually eliminates solar space heating systems which currently have fairly long payback periods; some packaged, mass-produced domestic hot water systems can have low payback periods (5 years or less) <u>if</u> they replace high cost (relative to gas) fuels such as electricity, and have low initial purchase and installation costs. Consumers are often wary in making investments in fixed heating equipment if the capital recovery period is longer than they plan to live in the house.[5]

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4 <u>Turn on the Sun</u>, p. 15. Appendix A-2 illustrates the methodology used for payback periods.

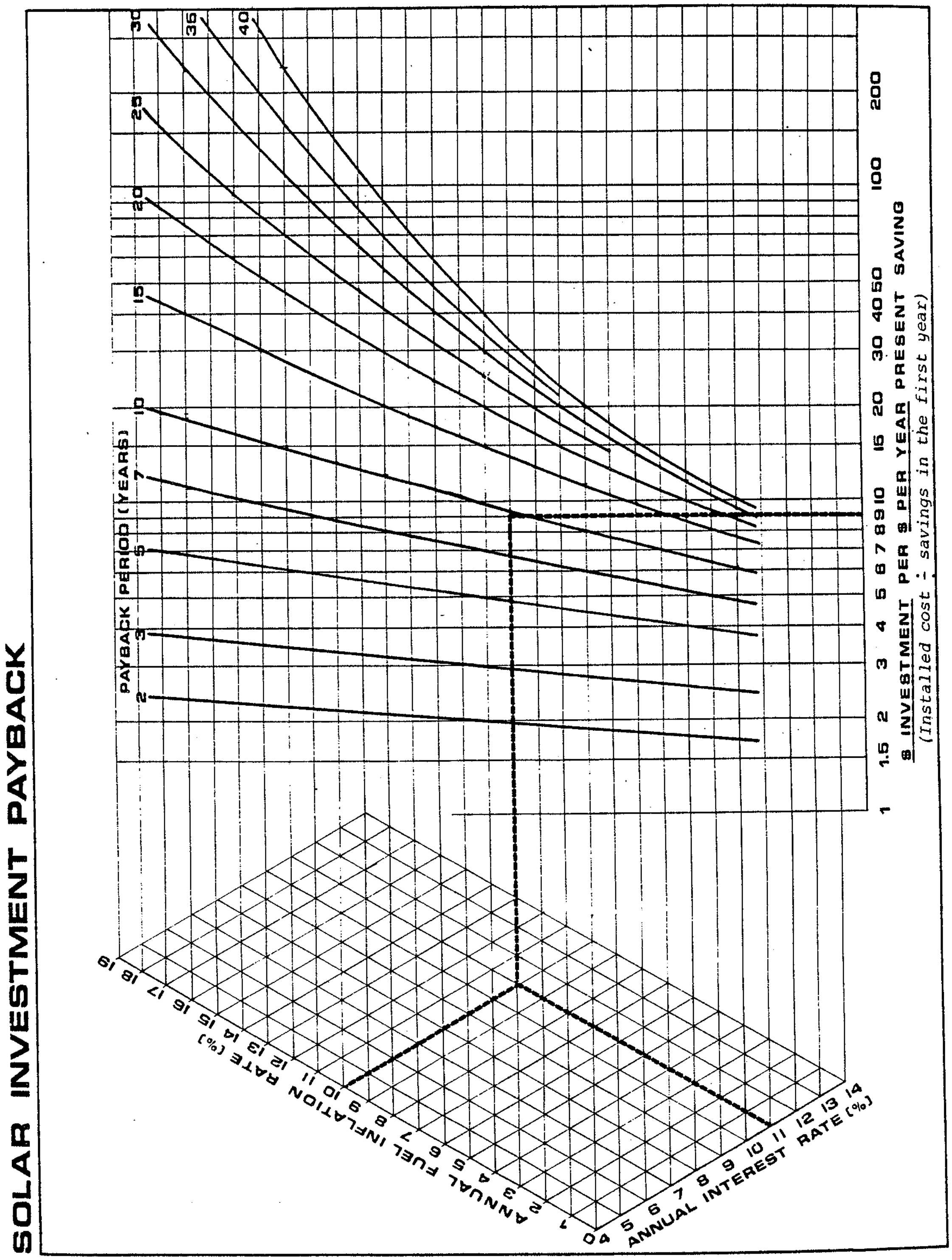
5 This housing ownership turnover rate will be to some extent, a function of the stability, age, and population characteristics of an existing area.

A very useful graph has been developed by the Drawing-Room Graphic Services Ltd. of British Columbia, illustrating some of the factors influencing the length of the payback period. Figure 30 illustrates that for any given combination of an annual interest rate and an assumed annual fuel inflation rate (left side of graph), that the ratio of the capital cost of a solar system to the first year fuel savings will yield a certain payback period. In the example used, an annual fuel inflation rate of 10% (i.e. home heating oil) and an annual interest rate of 11% (i.e. a preferred loan rate) are used. A system having capital costs of nine times the first years savings in fuel will yield a payback period of 10 years, e.g. a domestic hot water solar system costing $2,000 ($26/ft.^{2} for 75 square feet of collectors) in start-up costs saving $222 on the first year electrical utility bill. Assuming that the solar energy system in this case is providing 80% of the annual domestic hot water needs, the present electrical utility bill for hot water heating would be $\frac{\$222}{.80} = \$277.50$. Appendix A-3 illustrates some average costs for solar systems (swimming pool, domestic water, and space heating) calculated by B.C. hydro in 1980 dollars.

It should be recognized that any change in the above figures (interest rate, fuel escalation rate, ratio of capital cost to first year savings) will result in different payback periods.

4.3 LIFE CYCLE COSTING

The life-cycle cost of a heating system is "the total amount of money which must be budgeted for at the start of the first year of



Source: Solplan 2: Solar Energy for Existing Homes, R. Kadulski, et al., (Drawing-Room Graphic Services Ltd., Vancouver, B.C., July 1978), P. 37.

FIGURE 30: SOLAR INVESTMENT PAYBACK

operation to cover the initial capital cost and all the operating costs over the useful life of the system."[6] Life-cycle costing is an important concept for justifying an investment in solar energy at a much earlier date than would be possible on a current basis. It uses the well-established financial procedure of "discounted cash flow," taking into account the present value of annual system costs (initial capital and annual operating) and benefits (grants, tax savings, and conventional fuel savings). Costs incurred in the future are translated into current dollars (present value) by means of a discount rate, usually the mortgage rate.[7]

The prospective solar user should make a comparison between the present value of the lifetime solar costs and the conventional energy supply that the solar energy system replaces, just as the corporate decision maker compares the present worths of mutually exclusive investment opportunities.[8] The higher initial costs and zero fuel costs (other than operating costs) of solar energy systems introduce an emphasis on life-cycle costing that will probably require special government incentives, or participation by major utilities (hydro, natural gas) in order for the consumer to adapt solar energy to his present home. A number of solar heating applications can be economically feasible on a life-cycle basis, such as solar heating of swimming pools, domestic hot

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6 Turn on the Sun, p. 15.

7 Private industry would normally expect a higher rate of return than the mortgage interest rate in choosing solar energy as an investment possibility.

8 Implementing Solar Technology in Canada, M.K. Berkowitz, (Energy, Mines and Resources Canada, 1977), p. 9.

water systems, and some space heating systems. However, the cost-effectiveness of these systems, particularly space heating applications supplying a large fraction (40 to 60%) of a dwelling's heating requirements, is highly dependent on the method and factors included in the life-cycle costing calculation, as indicated in Section 4.1.

Appendix A-4 illustrates the life cycle costing methodology, together with the yearly cost, cumulative cost and cumulative present value of owning and operating three types of active heating systems: a conventional electric heating system, a custom-built solar heating system with electrical back-up, and a packaged solar heating system (a backyard solar furnace) with electrical auxiliary.[9] The life-cycle cost of the three systems is the total cumulative present value of owning and operating the systems over the economic life (twenty year amortization period). Comparison of life cycle costs between the systems will determine which system is preferable (least cost); the examples in Appendix A-4 indicate that the packaged solar heating system has the lowest cumulative present value costs over the 20 year amortization period.[10] Figure 31 illustrates the graphic relationship between the costs of these three systems.

Table 21 summarizes the composite life cycle costs for single-family residential solar space and water heating, or domestic hot water

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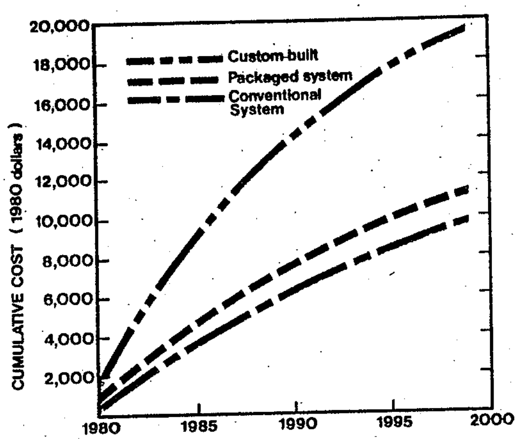
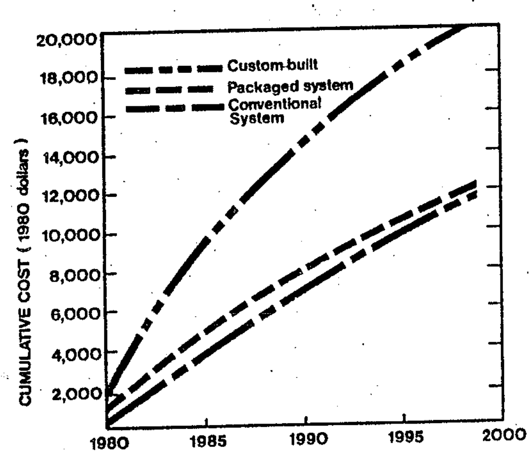
9 Source: Turn on the Sun, p. 42-43.

10 Assumptions included in this example: an annual fuel escalation rate of 10% for electricity; a 20 year amortization period at 10% per annum.



CUMULATIVE COST OF OWNING AND OPERATING THREE HEATING SYSTEMS (FUEL COST ESCALATION 7% PER ANNUM)

Even assuming fuel escalation of 10% per annum, the life cycle cost is still lowest for the conventional system and greatest for the custom-built system.



CUMULATIVE COST OF OWNING AND OPERATING THREE HEATING SYSTEMS (FUEL COST ESCALATION 10% PER ANNUM)

Source: Turn on the Sun, (Ontario Ministry of Energy, Toronto, October 1978), P. 15.

FIGURE 31: CUMULATIVE COST OF OWNING & OPERATING 3 HEATING SYSTEMS

only, on a regional basis in Canada.[11] In order to accurately determine the regional cost-competitiveness of solar space and/or water heating, projected life-cycle costs for existing residential heating systems can be compared as follows:

Table 21: Summary of Composite Life Cycle Costs ($ 1978) ($1,000/Unit)

REGION	SF Space + Water	SF (New) Water	SF (Retrofit) Water	Refrofit - or Contingency Factor
Atlantic	15 - 16	4.1	4.8	17%
Quebec	15 - 16	3.9	4.6	18%
Ontario	14 - 15	4.0	4.7	18%
Prairies	16 - 18	8.7	4.4	19%
B.C.	13 - 14	4.1	4.7	15%
Canada	13 - 18	3.7-4.1	4.4-4.8	15-19%

Source: Solar Heating & The Oil, Gas and Electricity Industries, p. 69.

Given these figures, it has been calculated that solar domestic hot water heating is on the borderline of becoming economically viable under certain conditions, but this will be mostly dependent on the type of fuel replaced (oil, gas or hydro).[12] Solar domestic hot water systems partially replacing low-cost natural gas water heaters may not be currently economically viable until such factors as capital grants, low mortgage rates (subsidized), and assumed high real fuel escalation rates are brought into the calculation of life-cycle costs.

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11 Table derived from Table 6.1 of Solar Heating and the Oil, Gas and Electricity Industries, (Energy, Mines and Resources Canada, Ottawa, 1979), p. 69. Space and hot water system is assumed to meet 70% of residential heating needs. Domestic hot water only systems are assumed to meet 50-75% of hot water heating needs.

12 Solar Heating Catalogue No. 2., (Energy, Mines and Resources Canada, Ottawa, 1979), p. vi.

An additional prohibitive factor for active solar system retrofits of existing houses vs. new houses is the higher initial capital cost, due to greater installation and material costs (i.e. structural strengthening of the roof, additional piping, modification of the basement to accommodate heat storage tanks, etc.). Most life-cycle costing comparisons of solar heating systems have been done for newly-constructed houses, but a contingency factor of 15-20% can be added to the life-cycle costs (primarily first year capital costs) for retrofit cases, as has been done in Table 21 for the domestic hot water retrofit case.

Few detailed studies have been done to date for passive solar retrofitting of existing Canadian Housing. Costs can vary widely depending upon the nature of the alterations made, the passive system employed (window wall, attached greenhouse, mass wall, or thermosiphon), the existing construction of the house, and the amount of additional useful solar gain that results. Life-cycle costs studies done for new houses where the passive system (including high insulation levels) can be incorporated at the design stage are not strictly comparable to the passive solar retrofitting of existing houses, due to the wide variability of factors cited above.

The passive solar retrofitting of a house can cost less than an active space and water heating system, but will probably result in a lower contribution (40% or less) to heating requirements than an active liquid system (40 to 60% or more). The capital cost for passive solar retrofitting will be dependent on what advantages an existing house can contribute, such as a south-facing solid masonry wall (mass wall system or thermal storage for an attached greenhouse), or its suitability for increasing the area of south-facing windows (window wall system).

Table 22 illustrates the relationship between the present value savings or costs and the choice of fuel escalation rates and social discount rates (mortgage rate or other) for two types of passive solar homes in Winnipeg. Solar Home A represents an additional investment of $3,500 over a conventional house costing $70,000, while Solar Home B represents an additional investment of $6,000 for the same house.[13] Solar Homes A and B yield present-value ($1979) savings only under the following conditions.

Table 22: Summary of Conditions Yielding Present Value Savings for Two Passive Solar Houses

TYPE (Investment)	TERM	DISCOUNT RATE	REAL FUEL ESCALATION RATE*
A ($3,500)	5 years	< 18%	> 2%
	25 years	< 18%	>-2%
	50 years	< 18%	>-2%
B ($6,000)	5 years	-	-
	25 years	< 14%	> 2%
	50 years	< 9%	>-2%

* Annual inflation rate of 8% was assumed.

> = greater than
< = less than

Source: Derived from Table 3-2, A Solar Energy Subdivision: An Assessment of Selected Institutional Barriers to Solar Energy in Winnipeg, T. Shillington.

13 A Solar Energy Subdivision: An Assessment of Selected Institutional Barriers to Solar Energy in Winnipeg. T. Shillington, (Natural Resource Institute, University of Manitoba, Winnipeg, April 1979), pps. 50-52.

While it is recognized that the present value savings for the alternate investments of $3,500 (Type A) or $6,000 (Type B), are not strictly comparable to the passive solar retrofitting of an existing house, it can be seen that the smaller investment yields present value savings sooner and under higher discount rates. It is also difficult to separate costs not strictly included in a passive solar retrofit, such as added insulation or the benefits of additional floor area obtained in an attached sunspace. Thus, the investment attractiveness of a passive solar retrofit of an existing house cannot be specified to the extent of that of an active system retrofit (including a cost contingency factor), and should be examined on a house by house basis.

4.4 EVALUATION OF FINANCIAL INCENTIVES

The higher initial capital costs and zero fuel costs of solar systems will introduce an emphasis on life-cycle costing, most likely requiring special incentives to produce adequate market penetration. The United States and Canadian experience to date in the solar technology delivery system have been quite different. The United States have placed a greater emphasis on the overall technology delivery system, particularly with respect to federal tax incentives and consumer grants, while in Canada more preliminary emphasis has been placed on funding support for manufacturers' research and development programs, demonstration installations, and sales tax incentives. In both countries, solar heating has been treated as a "consumer good rather than a utility service," while ensuring that the energy utility companies do not "actively prevent the adoption of solar home heating ... through punitive rate structures for back-up systems."[14] In addition, focus has been placed on the beneficial environmental impact of substituting solar energy for fossil fuels (as discussed in Chapter I), and the resultant effect on the supply-demand scenario for these conventional fuels.

Energy, Mines and Resources Canada conducted a study in 1977 on the effect of financial incentives on the lifetime cost of standardized and custom-designed solar systems for single and multiple family dwellings. The study concluded that the financial incentives that would have the largest effect of reducing life-cycle costs for a single-family standardized solar system, in decreasing order of importance were:[15]

1) Inclusion of the system value in property tax assessment.[16]
2) Mortgage interest tax deductible.
3) Depreciation tax deductible.
4) Lump sum payment (capital grant).
5) Mortgage interest rate subsidized
6) Maintenance cost tax credit
7) Depreciation tax deductible (25 years)
8) Maintenance cost tax deductible

The study was conducted for a standardized space-heating system (supplying 70% of the heat requirments) in a single-family Toronto residence,

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14 M.K. Berkowitz, p. 30.

15 M.K. Berkowitz, pps. 32, 34, 200.

16 The example used for property tax assessment was Toronto.

for both existing oil and electric space-heating systems.

Table 23 illustrates the lifetime costs of solar vs. oil and solar vs. electricity and the break-even values for mortgage rates and fuel price escalation rates. It is interesting to note that the standardized solar space heating system had lifetime costs greater than that of the oil heating system, but significantly lower than that of the electric heating system. Inclusion of the solar system value in property tax assessment resulted in lifetime costs 150% that of the oil heating system, but still lower than the lifetime costs for the electric system (about 87% of the electric lifetime costs).[17] Thus, the solar space-heating system was not competitive with the conventional oil-heating system whether included or not included in property tax assessment, while the solar system was more competitive than the electric space-heating system for both cases. However, exemption from property tax assessment made the solar system more competitive when compared for both the oil and electric heating systems.

It should be noted that higher mortgage rates will more heavily discount future fuel savings, thus reducing the present value savings of lifetime fuel saved. The solar vs. electricity case requires a break-even value for the mortgage rate of 16.1%; mortgage rates higher than this will make the solar space-heating system non-competitive with respect to the electric heating system, even when the system value is exempt from property tax assessment. In the solar vs. oil case, an annual fuel escalation rate higher than the breakeven value of 9.1%

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17 Figures were derived from Table 2-10, p. 32, Implementing Solar Technology in Canada, M.K. Berkowitz, 1977.

Table 23: Standardized System Lifetime Cost Comparison: Solar Equipment Exempt From Property Taxes

	Solar	vs.	Oil	Solar	vs.	Electricity
CAPITAL COST ($ 1977)	$6,884			$6,884		
Annual Mortgage Payment	740			740		
Mortgage Rate	10.0%			10.0%		
INITIAL ANNUAL FUEL BILL			407			696
Fuel Price per Unit			$ .69/gal.			$ .035/kwh
Fuel Escalation Rate			6.0%			6.0%
LIFETIME COSTS	$7,960		$6,600	$7,960		$11,280
BREAK-EVEN VALUES						
*Capital Cost/Month	$5,543			$10,136		
Mortgage Payment	597			1,090		
*Mortgage Rate	7.3%			16.1%		
Fuel Price per Unit			$ .83/gal.			$ .025/kwh
*Fuel Escalation Rate			9.1%			0.9%

* Determining Factors

Source: Implementing Solar Technology in Canada, M.K. Berkowitz, p. 34.

NB: The standardized system used in this example is a solar space-heating system supplying 70% of the annual heat requirment in a single-family Toronto residence.

would make the solar system more competitive with respect to the oil system, as the present value of lifetime fuel savings would be higher.

The 1977 study by Energy, Mines and Resources Canada determined that the inclusion of the value of a solar system in a property's tax assessment was a prime determinant of a system's cost-effectiveness. A range of financial incentives and the means by which they can be accomplished, will be presented in section 4.6 "Conclusions and Recommendations" indicating that financial incentives are largely the domain of provincial and federal governments.

4.5 EVALUATION OF CASE STUDY AREAS

Section 3.4 evaluated the retrofit suitability of two Winnipeg case study areas in terms of physical criteria such as solar access, roof form/angle, thermal insulation, heat storage volume, and the existing heating system and fuel type. As an outcome, Table 19 summarized the retrofit potential for the study areas of Sargent Park and Riverview for passive and active solar energy systems. The evaluation of the above physical criteria indicated that for Sargent Park, passive retrofit potential was very low due to poor solar access, however that active retrofit potential for space and water heating systems was good (20 to 60%) depending on the amount of south-facing roof area available. It was concluded that in Riverview that passive systems had a retrofit potential (market share) for 30 to 50% of all houses, while active systems had an even higher retrofit potential of 60 to 80% due to good solar access and availability of south-facing collector areas.

Chapter 4 has since explored the factors affecting the financial evaluation of solar energy systems, which will in turn affect the percentage of houses that will adopt a solar energy system. Mathematically, this can be expressed as:

% of market share = % of houses with physical retrofit potential x take-up rate due to financial factors

ie) for Active Water heating in Riverview:

% of market share = 80% (physical retrofit potential) x 40% take-up rate

Therefore, % of market share = 32%

This indicates that as a combination of physical and financial factors, approximately 32% of all houses in Riverview would adopt solar hot water heating systems. The 40% take-up rate assumed in the above sample is a hypothetical rate, and could be higher or lower depending on a number of economic factors. These factors have been previously identified as:

1. Capital costs of the solar heating system
2. Operating costs
3. Collector efficiency (% contribution to space and/or water heating load)
4. Government grants (towards initial capital costs)
5. Preferred loan rates (government subsidized)
6. Exemption from property tax assessment
7. Cost of conventional fuel replaced and assumed price escalation rate
8. Deductibility of capital and/or operating costs through tax schedule

It can be seen that as a result of the combination of physical and financial factors, certain types of solar energy systems (passive vs. active, space vs. water heating) will tend to achieve market "niches" in certain urban areas. In Sargent Park, given financial suitability, a market presence would likely be achieved first for active air systems with eutectic salt storage (due to space limitations), and secondly for active water heating systems (given sufficient roof collector area). For Riverview, a market presence would likely be achieved first for passive attached sunspaces/greenhouses due to good solar access, and secondly for active water and/or space heating systems due to the availability of south-facing collector areas.

In both study areas, the current and projected cost for natural gas (which has about 85 to 90% market share) will be a major determining factor for the financial viability of solar energy systems. An additional important factor that has been previously identified is the housing age and thermal efficiency (insulation levels). It was concluded that the thermal upgrading of existing housing was necessary to improve the cost and operating efficiency of a retrofit solar energy system, so that the contribution to heating loads would be higher, and capital requirements for collection areas and heat storage volumes would be minimized.

4.6 CONCUSIONS AND RECOMMENDATIONS

A number of important constraints to implementation have been identified in Chapter 4 through the analysis of financial factors affecting life-cycle costs of solar energy collection. It can be concluded then that the competitiveness for a solar space heating system with respect to a conventional system (oil, electricity, or natural gas) is highly dependent upon the interaction between the values assumed for:

1. The high initial capital costs of solar space and water heating systems, resulting in extended or non-existant payback periods.

2. The present high market penetration (85 to 90%) of natural gas heating systems in Winnipeg, resulting in lower or zero present value fuel savings for solar energy collection systems due to the relative price advantage of natural gas over oil, hydro or solar as a home heating fuel.

3. High discount rates employed to determine net present value savings of fuel, as a function of high inflation and mortgage rates. Decreased discount rates increase present value savings and result in decreased payback periods.

4. Lack of specific financial incentives to lower life-cycle costs and decrease payback periods, which could result in increased market penetration of solar energy collection systems.

5. Existing house construction and its effect, negative or positive, on installation, material costs, and solar component sizing and location.

6. The projected fuel escalation rates for conventional fuels (gas, oil and hydro) - the higher the assumed fuel escalation rate, the sooner a solar energy collection system becomes cost-effective (decreased payback period); and, the inaccuracy of projected fuel escalation rates due to changing government pricing policies, and changing supply-demand conditions for conventional fuels.

7. Attitude: Public acceptance of solar systems, given the right financial paybacks, may still be a deterrant to implementation due to lack of consumer information, lack of technology credibility, etc.

The most effective financial incentives to lower life-cycle system costs to the consumer should be adopted, in particular removal from property tax assessment and amortization of capital costs through the income tax system. Selection of specific financial incentives will

Table 24: Policy Recommendations for Financial Incentives

POLICY	MECHANISMS	RESPONSIBILITY AREA			
		Municipal Government	Provincial Government	Federal Government	Other
Financial					
1. Remove the value of a solar energy collection system from property tax assessments	. change laws and enforce		X (1977) Manitoba		
2. No sales tax on solar equipment and related controls.	. change laws		X	X	
3. Tax credits through amortization of capital costs	. change income tax regulations		X	X (1978: U.S.)	
4. Preferred loan rates to finance capital costs of solar energy systems	. government loan guarantees		X	X (1979: U.S.)	Financial Institutions
5. Capital grants/ subsidies	. government programs and matching grants		X	X (1975) (COSP)	
6. Capital system costs amortized by utility bill payments	. utilities to become suppliers of solar energy systems				Utilities (gas, hydro)
7. Non-discriminatory utility rate price structure for back-up supply	. regulation by government		X		Utilities

depend on their net effect on the rate of solar market penetration, and the net costs to government in terms of administration, environmental impact, and net fuel savings.

Table 24 outlines specific policy recommendations that would permit an increased rate of solar retrofit of active and passive systems for existing housing. It can be seen from Table 24 that financial incentives to encourage the retrofit of solar energy collection systems fall within the domain of the provincial and federal governments, and to a limited extent can involve the participation by financial institutions and energy utility companies. Table 24 also indicates which policy recommendations (financial incentives), and the date of their implementation, that have been partially adopted either in the United States or in Canada.

A critical aspect of the cost-effectiveness of solar system retrofits is that for a given sum of money, how much should be used for reducing overall energy consumption through thermal upgrading and how much should be used towards producing an additional source of energy (solar retrofit)?[18] If the present discounted value of a solar retrofit's savings are <u>less</u> than the initial capital outlay of the retrofit, then greater economic benefit would be gained by investing in some form of energy conservation. The alternative investment in energy conservation measures would yield a higher rate of return than the solar retrofit. Thus, solar space heating retrofits, either active or passive, should only be considered after extensive thermal upgrading of the building.

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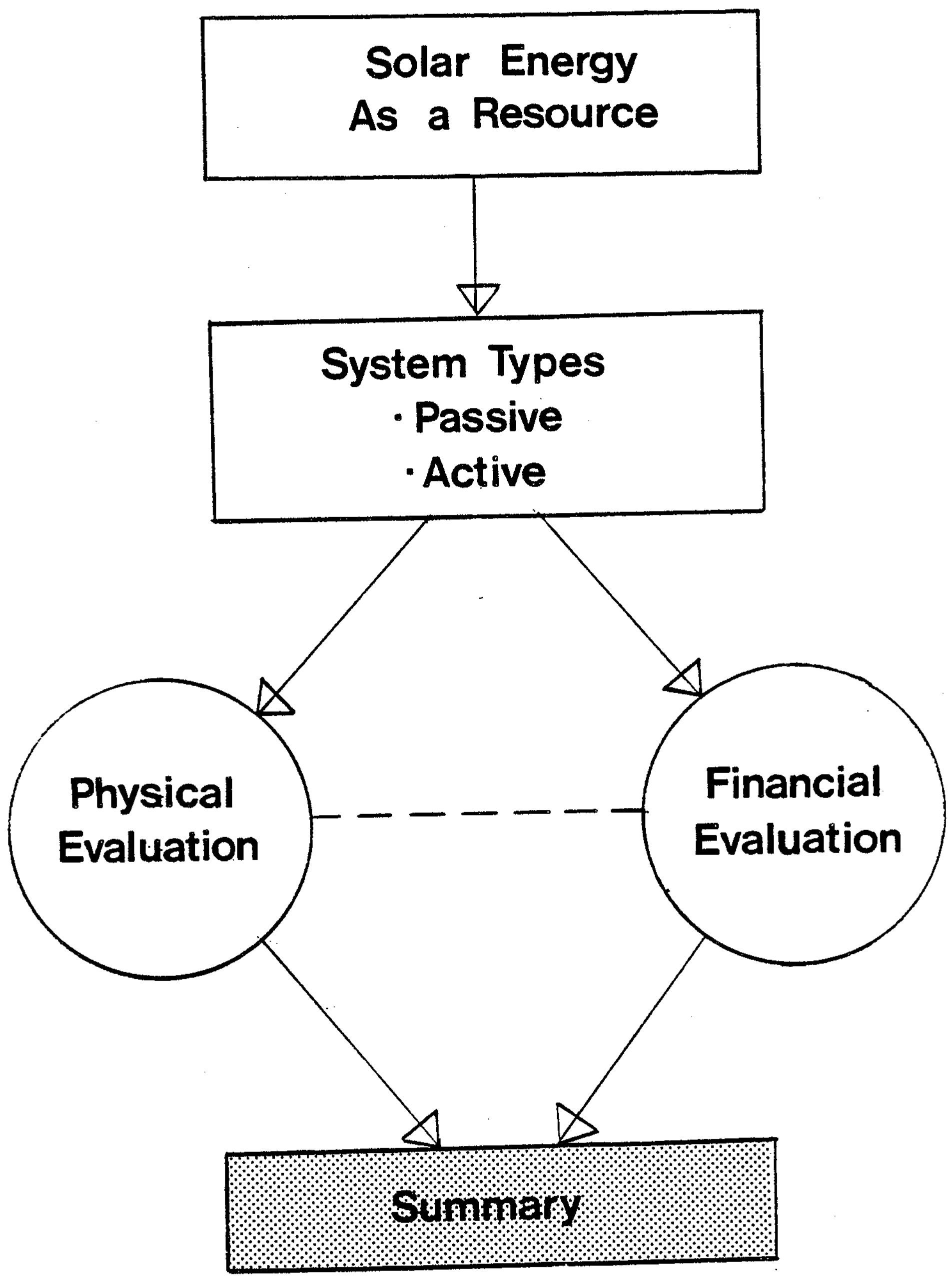
18 Residential Solar Retrofit in Canada, IBI Group, Hooper & Angus Associates, (Energy, Mines and Resources Canada, Ottawa, November 1979), p. 31.

SUMMARY: PROSPECTS FOR SOLAR ENERGY



STRUCTURE

SUMMARY: PROSPECTS FOR SOLAR ENERGY

This thesis has identified three major arguments for the utilization of solar energy, particularly with respect to housing:

1) Environmental impact minimized
2) Positive effect on gross energy demand and supply
3) Potential cost attractiveness to the consumer on the basis of life-cycle cost or payback period.

The potential for solar energy retrofit of existing urban areas has been outlined as a function of the physical and financial characteristics of solar energy collection systems, and as a function of the design characteristics of existing "neighbourhoods" by means of a case study. Limiting factors have been analyzed as to their effect on ultimate retrofit potential, as determined by active and passive system types and their interface with existing houses. Policy recommendations to encourage the adoption of space and water heating were broadly classified into "financial" and "physical" categories. Certain mechanisms to implement these recommendations were discussed, particularly with regard to legal mechanisms (and their limitations) to protect solar access in existing urban areas and financial incentives to encourage the use of solar energy systems. The market potential of solar energy for existing housing will ultimately be a function of the location and design of built-up urban areas, the technology of solar energy collection systems and their interface with existing houses, and the costs involved to implement these systems.

While the case study was confined to two Winnipeg "neighbourhoods" primarily as a function of lot orientation, ultimately this type of study could be extended to entire urban areas. The solar "retrofit" potential for certain cities could then be determined as function of regional climate, latitude, physical layout, housing type and construction, and existing fuel market penetration. It can be concluded from the case study that certain mechanisms to protect solar access in existing areas, combined with the types and rate of implementation of financial incentives, will ultimately determine the upper limits of solar market penetration. It was seen that certain legal mechanisms were more appropriate for existing areas vs. new subdivision design in order to provide some measure of protection for solar access. Clearly, certain urban areas will benefit more than others, because existing physical conditions are more suitable for solar retrofit, and stronger degrees of control (i.e. "solar overlay zoning" categories) can be extended to these areas. As a result, should the use of solar energy for space and water heating have increased market penetration, certain urban areas will have differential benefits in terms of net fuel savings to their property owners. It is also possible that certain types of solar collection systems, active or passive, will find certain market "niches" as a function of the solar economics and physical characteristics specific to an urban area. These market niches for solar system types will also vary by region due to climatic differences (heating season, solar insolation) and the present fuel market penetration by fuel type and mode of heat distribution.

In a study for Energy, Mines and Resources Canada the Mitre Corporation, Metrek Division, developed a solar market penetration model based on the comparative costs of solar and conventional heating systems, taking into account that the choice of a solar energy system normally involves the selection of a backup energy supply. It is the combined effect of the choice of backup fuel (with some inter-fuel substitution) and the substitution of conventional fuels by solar energy that will determine the net impact on the demand for oil, gas and electricity by solar heating. The Metrek market share function, as illustrated in Figure 32, is derived from the hypothesis that the ultimate capture potential of solar energy is a function of the ratio of life cycle costs of a conventional energy system to that of a solar energy system.

The curves drawn in Figure 32 are based on mathematical values for a "Figure of Merit" (FOM) which is defined as "a measure of the competiveness of the new technology with respect to a conventional counterpart", and is calculated as the ratio of the life cycle costs (LCC) of competing technologies.[1]

$$\text{FOM} = \frac{\text{LCC (Conventional)}}{\text{LCC (Solar)}}$$

Figure 32 illustrates the projected solar market shares for three values of FOM (.5, 1.0, 1.5) indicating the market penetration response of solar energy as a function of the ratio of conventional (oil, gas, or hydro) and solar life cycle costs.[2] As solar energy system life cycle

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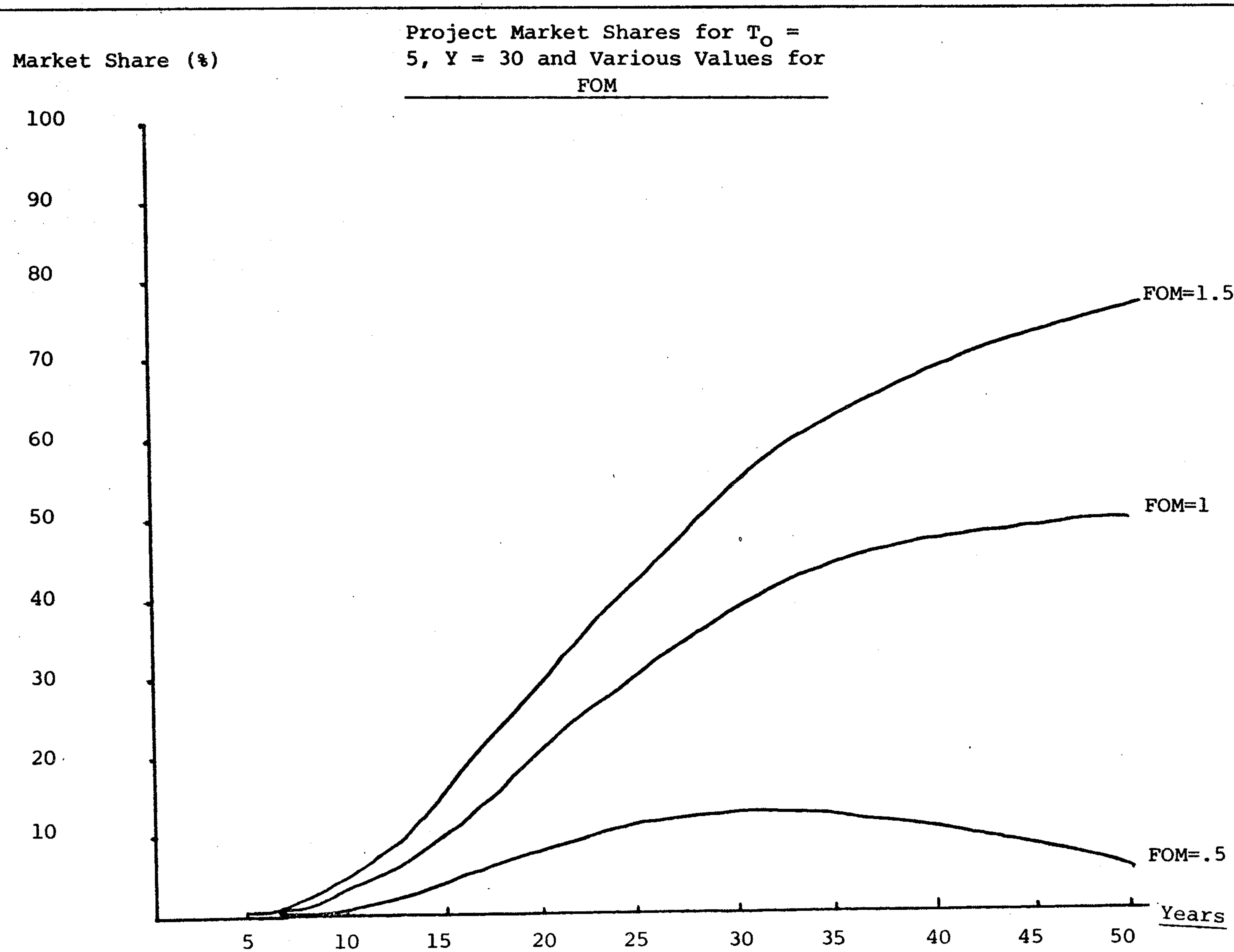
1 Solar Heating and the Oil, Gas and Electricity Industries, p. 57.

2 Life-cycle costs should be defined to include government grants and tax write-offs to the consumer in order to reduce initial capital outlays and operating expenses.



Source: <u>Solar Heating and the Oil, Gas and Electricity Industries</u>, (Energy, Mines and Resources Canada, Ottawa, 1979), P. 58.

FIGURE 32: PROJECTED MARKET SHARES FOR SOLAR ENERGY

costs decrease with respect to conventional energy system costs (FOM increasing), the market share captured by solar energy increases.

The Metrek market share function was then used to derive market shares for each type of solar technology (space and water heating, water heating only, single family vs. multiple family, new vs. existing housing) in relation to each of the conventional energy markets. This is calculated by several formulas accounting for competition among back-up fuels, system size, design options and the storage/collector ratio (see Appendix A-5). Table 25 "Market Penetration Summary", illustrates the degree of solar penetration (low oil price scenario) into conventional markets for the year 2000 on a regional basis. The table indicates that within the next twenty years, the greatest market penetration of solar energy will be in hot water only systems for new housing, with market shares varying between 20.6% (Prairies, gas) and 41.0% (Ontario, electricity) depending on the region and the existing fuel. Single-family water heating retrofits will vary between a cumulative market share of 12.6% (gas) and 20.7% (electricity) in the Prairie region, assuming an annual retrofit rate of .23% for the existing housing stock. Due to the size of the "existing" housing market relative to new house construction, incentives to increase this low annual retrofit rate for existing stock would have a much greater effect on total residential energy supply than the rate of implementation in the new housing sector.

Table 25: Solar Market Penetration Summary for the Year 2000
(Low Oil Price Scenario)

% Penetration	Comb. SF/MF S + W Total (Annual)	SF:W Retrofit (Cumulative)	MF:W Retrofit (Cumulative)
ATLANTIC			
Oil	13.7	24.5	8.7
Gas	-	-	-
Electric	16.0	26.8	13.4
QUEBEC			
Oil	14.8	27.9	10.7
Gas	8.3	19.7	8.6
Electric	15.2	27.8	14.6
ONTARIO			
Oil	13.6	26.4	10.0
Gas	7.4	18.3	7.9
Electric	16.7	29.3	15.8
PRAIRIES			
Oil	11.8	18.7	4.8
Gas	6.5	12.6	3.6
Electric	14.5	20.7	7.4
B.C.			
Oil	9.1	21.5	7.0
Gas	4.4	14.0	5.2
Electric	11.6	24.6	11.5

SF: Single Family
MF: Multiple Family
S: Space Heating
W: Water Heating

Source: Derived from Table 6.4, Solar Heating and the Oil, Gas and Electricity Industries, (Energy, Mines & Resources Canada, Ottawa, 1979), p. 74.

The general trends indicated by this market penetration summary are:[3]

1) By the year 2000 on a cumulative basis, projections indicate that between 1 in 4 and 1 in 8 single family dwellings will have been retrofitted with solar water heating.

2) Multiple family solar water retrofits have a much slower cumulative market penetration, between 1 in 30 and 1 in 6 under the most optimistic circumstances.

3) For new multiple family buildings, solar water heating should capture 10.3 to 30.1% of the conventional market by the year 2000.

4) Market shares for solar water heating systems in new single family dwellings vary from 20% to 40%, largest in Quebec and Ontario, and smallest in the Prairies as it is difficult for solar to displace natural gas, where solar energy market penetration will be about two-thirds of that achieved in the oil and electricity markets.

5) In all regions, solar heating displaces electric space heating to a greater extent that either gas or oil because of a price advantage. Penetration into the gas space heating market is projected to be only half of that for oil and hydro, due to the lower price of gas.

6) Depending on the location, fuel, and building type, the solar space and water heating market share in single and multiple-family dwellings ranges from 4.2% to 16.7% on an annual basis. The implementation rate in single-family dwellings is only slightly higher than that for multiple-family dwellings.

These market projections do indicate the extent to which solar heating can make a significant contribution to residential space and water heating in Canada by the year 2000. The market penetration model illustrates that the projected annual and cumulative market shares (for new and retrofit applications, respectively) are a function of region,

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3 Solar Heating and the Oil, Gas & Electricity Industries, p. 75.

the type of conventional fuel displaced, the backup fuel chosen, the type and application of the chosen solar energy system, and the housing type (single or multiple-family). It must be recognized, however, that consumer preference for short payback periods on solar retrofit installations tends to outweigh the use of life cycle costs in estimating the future market potential of solar energy systems. In addition, the physical constraints to retrofit outlined in the Winnipeg case study will also tend to lower solar market penetration for certain urban areas where solar access can not be guaranteed.

It is interesting, at this point, to postulate what degree of importance solar energy will have in meeting future world energy needs. The U.S. Energy Research & Development Administration in 1977 developed a number of market share scenarios for world energy use, shown in Figures 33 and 34. Option A in Figure 33 represents the nuclear market share replacing fossil fuels by the year 2025, and assigns a declining share of the market to nuclear energy after 2025, with solar replacing nuclear by the year 2050. Figure 34 illustrates two additional scenarios, with solar gradually replacing nuclear by 2050 (Option A); and with solar replacing nuclear by 2100, but assuming a much higher rate of growth for energy demand (non-conservation scenario).

Ultimately, the "social acceptability of solar heating and cooling systems will depend on their economic viability, reliability, aesthetic impact and their public image as a clear, convenient and suitable source of comfort conditioning".[4] It is recognized that "... over the next

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4 Solar Energy: Project Independence, (U.S. Federal Energy Administration, Washington, D.C., 1974), p. II-59.

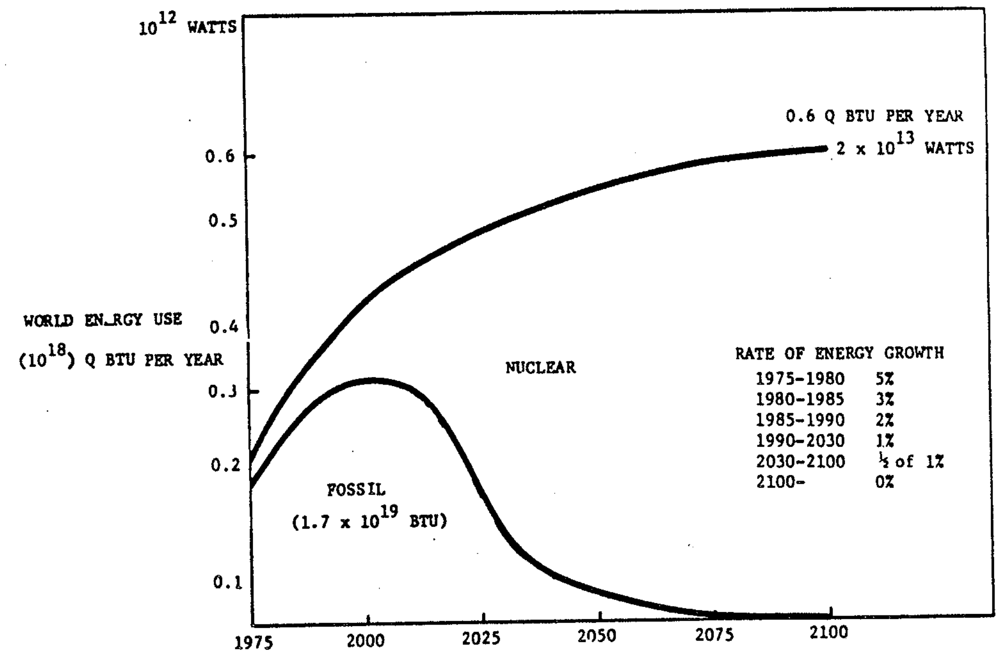
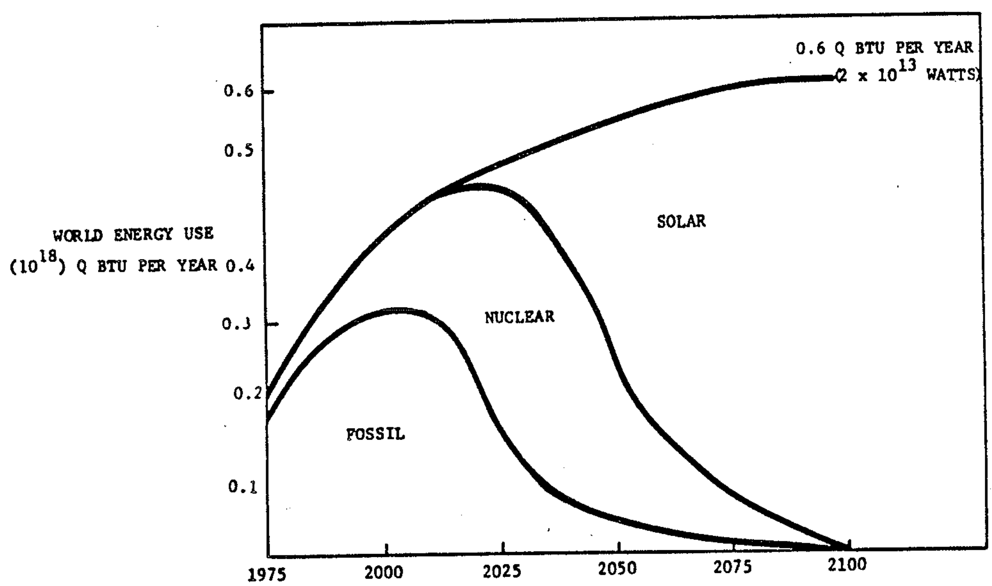


FIGURE 10

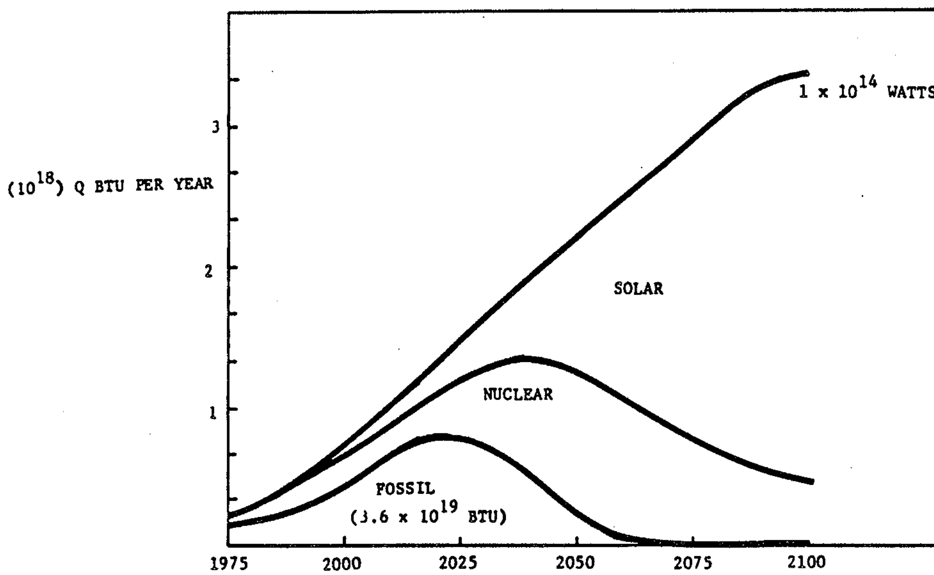
OPTION A. NUCLEAR REPLACES FOSSIL BY THE YEAR 2025



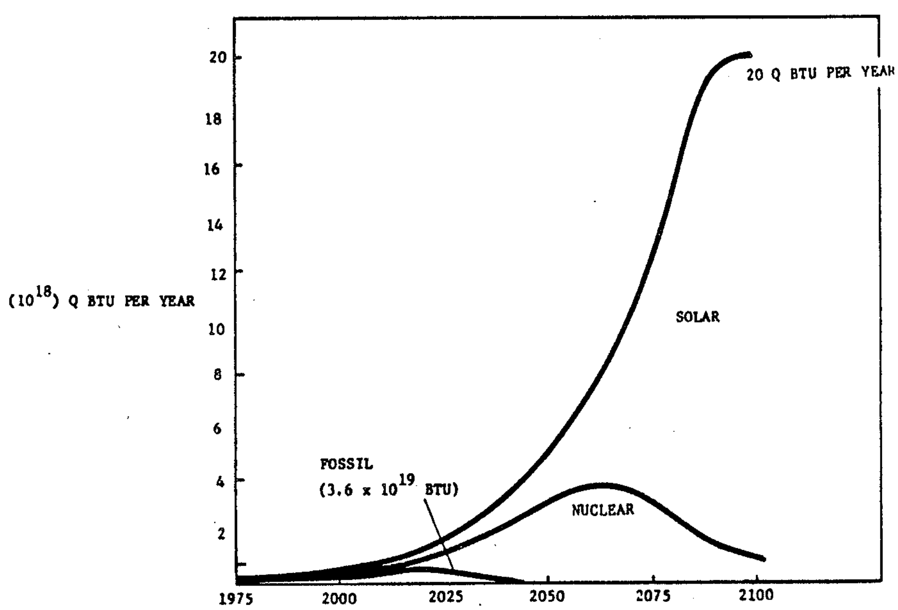
OPTION B. SOLAR REPLACES NUCLEAR BY THE YEAR 2050

Source: Solar Energy: Project Independence, (U.S. Federal Energy Administration, Washington, D.C., 1974), P. A-II-40 & 45.

FIGURE 33: WORLD ENERGY SUPPLY SHARE SCENARIO (PART I)



OPTION SOLAR REPLACES NUCLEAR ~ 2050



OPTION B. SOLAR REPLACES NUCLEAR BY 2100

Source: Solar Energy: Project Independence, (U.S. Federal Energy Administration, Washington, D.C., 1974), P. A-II-32 & 39.

FIGURE 34: WORLD ENERGY SUPPLY SHARE SCAENARIO (PART II)

fifteen years renewable sources are likely to make a relatively small impact on total energy consumption in Canada," as the cost of a solar energy system is still perceived as a major constraint to its implementation - in particular the high initial capital costs required and the lengthy payback periods for certain system types and applications.[5] This is particularly true for active space and water heating systems which have high start-up costs, while for passive heating systems (ie. attached sunspaces) which can be cost-efficient and provide an additional amenity to an existing house, the major constraint appears to be public attitude or consumer acceptance. However, in light of the negative externalities of conventional fuels and the proportion of space and water heating energy demand currently supplied by these fuels, it is apparent that a considerable contribution <u>can</u> be made by solar energy if physical, financial, and attitudinal constraints to its implementation are overcome.

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5 Energy Conservation in Canada: Programs and Perspectives, (Energy, Mines and Resources Canada, Ottawa, 1977), p. 5,6.

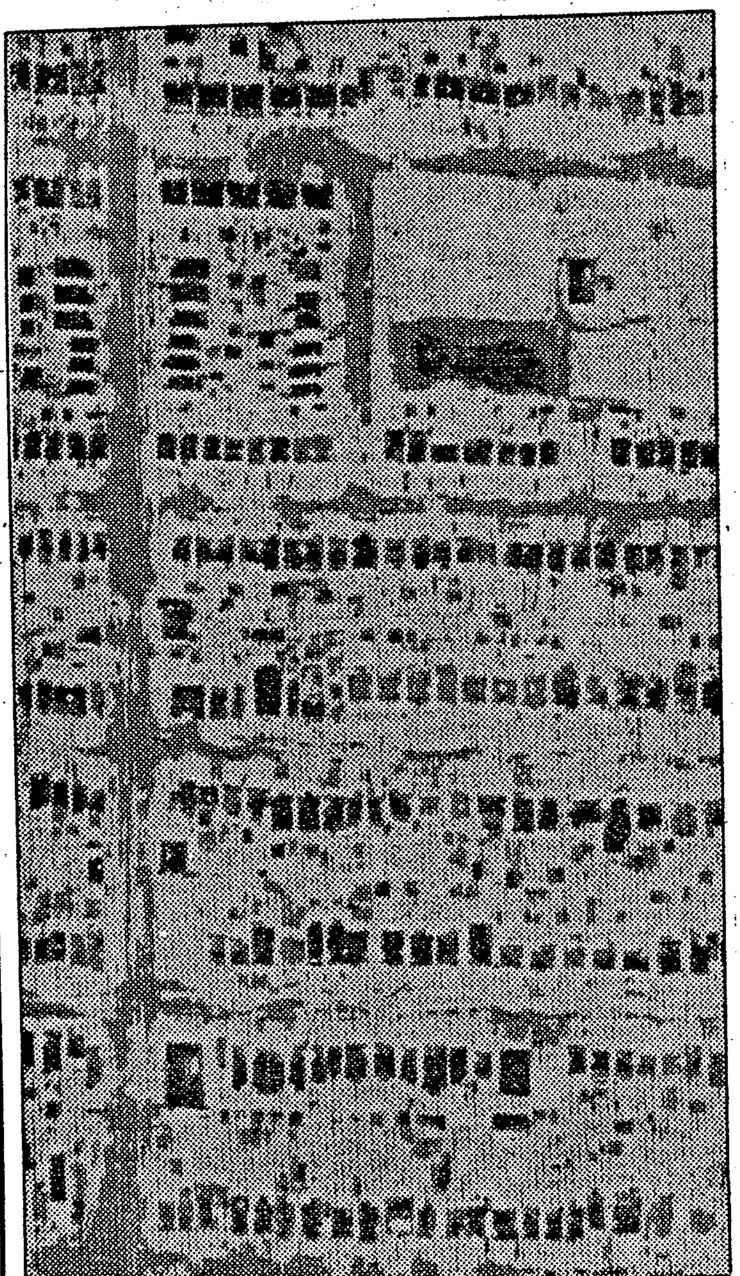
APPENDICES

APPENDIX A-1. AERIAL THERMOGRAMS: HEAT SAVE PLAN - TORONTO

Source: "Globe and Mail," Toronto, January 29, 1982.

Thermograms tell insulation story

Heat Save plan comes to Toronto



Thermogram of homes in Toronto shows rooftops as rectangles. Black means good attic insulation.

By MICHAEL KEATING

Photographs that look like fuzzy pictures on an old, black-and-white television set could save Ontario homeowners 30 per cent of their heating bills.

The pictures, calle thermograms, are taken from planes carrying infrared equipment that spots heat escaping from badly insulated houses.

By 1985, thermograms will have been produced for every city of 10,000 or more in the province. This will cover 62 per cent of the population, says Heat Save program manager John Quinn.

The arrival of the Heat Save project in Toronto was announced yesterday by Ontario Energy Minister Robert Welch. The program is part of a plan to improve the energy efficiency of every home in Ontario by 30 per cent by 1995, Mr. Welch said.

This winter, that would mean a $900-million saving on the $3-billion estimated fuel bill for Ontario homes.

The Heat Save program, which started in 1980, has so far covered 13 cities. After thermograms are produced, free citizens' clinics are held where homeowners can see how much heat is leaking through their roofs and get advice on improving their insulation to cut their heating bills. Attendance at the clinics has averaged 40 to 50 per cent.

The first Toronto clinics will start Monday. They will continue through the fall.

The Toronto meetings are not being advertised because people might flood them, an Energy Ministry official said. Homeowners in each section of the city will be invited to specific sessions by letter, so there will be enough advisers to spend 20 to 30 minutes with each one.

In Toronto the project will cost about $625,000 — $5.60 for each of the city's 111,000 houses. Since 85 per cent of Toronto's houses were built before 1930, officials expect to find plenty of room for increased insulation.

The program is limited to houses because, for technical reasons, it is difficult to apply to larger buildings, the Energy Ministry says. Large buildings can be inspected by special teams on request.

At the energy clinics, people will find thermograms giving rooftop views of every square inch of their neighborhoods. These temperature maps show rows of black rectangles. The black areas are the rooftops — and the blacker they are the better, because that means less heat is escaping through the roof.

But comparing one roof with a neighbor's is just the start. The thermograms only reveal heat loss through the top of the house.

People are asked to bring their house measurements and last year's heating bill. A calculator-wielding energy official will figure out how much heat each house is losing and make suggestions about how the situation could be improved.

According to Heat Save official Barry Davis, one of the biggest discoveries people make is that they lack enough roof vents to let normal moisture from the interior escape. Over time, moisture trapped in the attic can destroy insulation and rot the roof.

APPENDIX 2: PAYBACK PERIOD METHODOLOGY

For example, a retrofit system connected to an electrical back-up system for which the price of electricity is expected to increase at an annual rate of 9 percent would result in a FUEL ESCALATION RATE (e) expressed as a ratio:

$$e = 0.09$$

The DISCOUNT RATE (i), can represent the cost of borrowing money determined by the interest rate charged by the lender, or the return on interest one could realize by investing the capital spent on a retrofit in an alternate avenue of investment. In this case, i expressed as a ratio is:

$$i = 0.10 \quad \text{(or other investment/mortgage rate)}$$

The ECONOMIC LIFE (n), of the solar retrofits is the expected useful life of the solar system, i.e.

$$n = 20 \text{ years}$$

The PRESENT DISCOUNTED VALUE (PDV), or PRESENT WORTH (PW), of a system's fuel savings, gives the total amount of fuel saved over the lifetime of the system expressed as a lump sum in current dollars. The PDV of equal fuel savings over time is given by:

$$PDV_{savings} = \text{First Year Savings} \times \frac{R\,(R^n - 1)}{R - 1}$$

$$\text{where } R = \frac{1 + e}{1 + i}$$

The term $\frac{R(R^n - 1)}{R - 1}$, the PRESENT DISCOUNTED FACTOR, can be evaluated for any particular set of values for i, e, and n. If the PDV of a solar retrofit's savings are less than the present day costs of the retrofit, then from an economic point of view, greater economic benefit could likely be gained by investing in an alternate energy conserving system.

The PAYBACK PERIOD for a solar system occurs when the PDV of fuel saved by the system is equal to the incremental capital cost of the system. Payback is determined by the following expression:

PAYBACK occurs when:

Incremental Capital = (Fuel Saved in First Year of Operation) x (PDF for Fuel Saved)

$$\text{Capital} = \text{Fuel Saved} \times \frac{R(R^f - 1)}{R - 1}; \quad \text{where } R = \frac{1 + \text{escalation}}{1 + \text{discount}}$$

$$f = \frac{n((R \times (R-1) + 1)}{\ln R}; \quad \text{where } R = \text{capital cost of solar system}$$

and S = Fuel saved in First Year of Operation

Source: Residential Solar Retrofit in Canada, IBI Group, (Hooper and Angus Associates, Toronto, May 1979).

APPENDIX A-3: TYPICAL COSTS OF ACTIVE SOLAR SYSTEMS

APPLICATION	PRE-SOLAR CONSERVATION RECOMMENDATIONS	SYSTEM DESCRIPTION	AVERAGE COST OF SOLAR INSTALLATION
SWIMMING POOL HEATING	Use of pool cover	Inground outdoor pool 5 x 10 metres (16 x 32 feet). Collector area equal to 60% pool area.	\$2,500 — \$3,500
DOMESTIC WATER HEATING	Wrap tank with minimum of RSI 1.75 (R10) fibreglass batt.** Wrap hot water piping with 12 mm (0.5 inch) of fibreglass batt.	Two to four panels preheat storage tank; controls, pump.	\$2,000 — \$4,000
SPACE HEATING	Insulate and glaze to optimum recommendations. In the case of new construction, orient the main window area southward, use appropriate shading from overhangs or eaves and use insulated shutters.	As per experienced designer.	\$160 — \$380 per square metre. \$15 — \$35 per square foot or \$10,000 — \$20,000

* The above recommendations are listed in order of economic viability.
** DO NOT cover the controls. Further, in the case of gas and oil water heaters, DO NOT obstruct the vent connections or combustion air openings.

The above has been prepared for information only and B.C. Hydro does not in any way warrant or guarantee the accuracy of this material.

1980 APRIL: DVB/SFL
energy use engineering department

energy conservation division
B.C. Hydro

Source: Solar Energy, (B.C. Hydro, Energy Conservation Division, Vancouver, B.C., April 1980), P. S-1.

Life Cycle Costing Methodology

The life cycle cost of a building heating system is the total amount of money which must be set aside, at the start of the first year of operation, in order to cover the initial costs and all the operating costs over the life of the system. The general form of the life cycle costing equations for conventional and solar building heating systems is given below.

The life cycle cost of a conventional building heating system is defined as:

$$(1)\quad KC + \sum_{t=1}^{N} \frac{(EC.PC_t + MC_t)}{(1+i)^t}$$

The life cycle cost of a solar building heating system is defined as:

$$(2)\quad KR + \sum_{t=1}^{N} \frac{(EB.PB_t + MR_t)}{(1+i)^t}$$

where . . .

- N = the costing horizon. The life of the system — that is the period after which, due to deterioration or obsolescence, the system must be discarded — is usually used as the costing horizon.
  The comparison of alternate heating systems using the above life cycle costing equations is only valid when the costing horizon is assumed to be the same for all of the alternatives under consideration.
- KC = the capital cost of the conventional building heating system. This cost is assumed to be paid at the start of the first year of operation.
- KR = the capital cost of the solar building heating system, *including,* where applicable, the capital cost of a back-up conventional heating system. This cost is assumed to be paid at the start of the first year of operation.
- EC = the annual input energy requirement of the conventional building heating system. This reflects both the total heating energy requirements of the building and the conversion efficiency of the conventional system.
- EB = the annual input energy requirement of the back-up system for the solar building heating system. This is based on the portion of the building's total energy requirements which will not be provided by solar energy and the conversion efficiency of the back-up system.
- PC_t = the unit cost, in year t, of the energy used for the conventional heating system. This is assumed to be paid at the end of the year.
- PB_t = the unit cost, in year t, of the energy used for the back-up system to the solar heating system. This is assumed to be paid at the end of the year.
- MC_t = the maintenance cost, in year t, of the conventional building heating system. This is assumed to be paid at the end of the year.
- MR_t = the maintenance cost, in year t, of the solar building heating system, including, where applicable, the maintenance cost of the back-up system. This is assumed to be paid at the end of the year.
- i = the annual discount rate.
  Normally the cost of borrowing is used as the discount rate.

The payback period of a project is the number of years required for the cumulative net revenue to equal the original capital investment. This definition can be set out rather simply, using the previously defined parameters:

If PBP is the payback period (measured in years) then:

$$\sum_{t=1}^{PBP-1} (PC_t \bullet EC - PB_t \bullet EB) + \sum_{t=1}^{PBP-1} (MC_t - MR_t)$$

$$\leq KR - KC < \sum_{t=1}^{PBP} (PC_t \bullet EC - PB_t \bullet EB) + \sum_{t=1}^{PBP} (MC_t - MR_t)$$

As an example, a conventional electric heating system, a custom-built solar heating system with electrical back-up, and a packaged solar heating system (a backyard solar furnace), also with an electrical auxiliary, are compared under the following assumptions.

The capital cost of the conventional heating system is estimated at \$1,905 and requires \$15 for maintenance cost each year, which escalates at 7% per year. The conventional system requires 14,950 kWh of energy per year which is estimated to cost 3.6¢ per kWh in 1980 and will escalate at 10% per year after 1980. The custom-built solar heating system, including the electrical back-up, has a capital cost (in 1980 dollars) of \$15,575. This is equivalent to a capital cost of \$10,950 in 1976 dollars for the solar system plus the conventional back-up system. The back-up system requires 4,130 kWh of energy per year. The maintenance cost is \$135 per annum escalating at 7% per year. The capital cost of the packaged system, including the electrical back-up is estimated at \$5,440. This system requires 9,085 kWh of energy per year and the first year maintenance cost is \$40 inflating at 10% per year. The capital costs of all three systems were amortized over a twenty-year period at 10% per annum resulting in the following yearly payments:

a) Conventional System — \$ 224 per annum
b) Custom Solar Heating System — \$1829 per annum
c) Packaged Solar Heating System — \$ 639 per annum

Table No. 1 indicates the yearly cost of owning and operating each of the systems. Table No. 2 indicates the cumulative cost, in current dollars, of owning and operating each of the systems, which allows for the calculation of the payback period. Finally, Table No. 3 indicates the cumulative present value, in 1980 dollars, of owning and operating each of the systems.

The life cycle cost of the three systems is the total cumulative present value of owning and operating the systems over their life and can be obtained from Table No. 3.

Source: Turn on the Sun, (Ontario Ministry of Energy, Toronto, October 1978), P. 43.

Table No. 1
Yearly Cost of Owning and Operating Heating Systems
(Current Dollars)

Year	Conventional System	Custom Solar Heating System	Packaged Solar Heating System
1980	777	2113	1006
1981	832	2137	1042
1982	892	2164	1081
1983	958	2192	1123
1984	1032	2224	1170
1985	1112	2257	1222
1986	1200	2295	1278
1987	1297	2336	1340
1988	1404	2380	1409
1989	1521	2428	1484
1990	1650	2481	1566
1991	1792	2537	1656
1992	1947	2600	1755
1993	2118	2667	1864
1994	2307	2742	1984
1995	2513	2822	2115
1996	2741	2911	2260
1997	2991	3006	2418
1998	3267	3112	2592
1999	3570	3226	2784

Table No. 2
Cumulative Cost of Owning and Operating Heating Systems
(Current Dollars)

Year	Conventional System	Custom Solar Heating System	Packaged Solar Heating System
1980	777	2113	1006
1981	1609	4250	2048
1982	2501	6414	3129
1983	3459	8606	4252
1984	4491	10830	5422
1985	5603	13087	6644
1986	6803	15382	7922
1987	8100	17718	9262
1988	9504	20098	10671
1989	11025	22526	12155
1990	12675	25007	13721
1991	14467	27544	15377
1992	16414	30144	17132
1993	18532	32811	18996
1994	20839	35553	20980
1995	23352	38375	23095
1996	26093	41286	25355
1997	29084	44292	27773
1998	32351	47404	30365
1999	35921	50630	33149

Table No. 3
Cumulative Present Value of Owning and Operating Heating Systems
(1980 Dollars)

Year	Conventional System	Custom Solar Heating System	Packaged Solar Heating System
1980	706	1921	915
1981	1394	3687	1776
1982	2064	5313	2588
1983	2718	6810	3355
1984	3359	8191	4081
1985	3987	9465	4771
1986	4603	10643	5427
1987	5208	11733	6052
1988	5803	12742	6650
1989	6389	13678	7222
1990	6967	14548	7771
1991	7538	15356	8299
1992	8102	16109	8807
1993	8660	16811	9298
1994	9212	17467	9773
1995	9759	10881	10233
1996	10301	18657	10680
1997	10839	19198	11115
1998	11373	19707	11539
1999	11904	20187	11953

The Metrek market share function has the following characteristics:

1) an s-shaped, logistic curve with a rate of penetration in the early years which declines until an asymptote is reached, and

2) simulation of a certain market share in the early years even for a new technology which is not yet competitive. If competitiveness improves, its market share grows, otherwise the market share declines eventually to zero.

The market share equation, then, is defined as:

$$P = \frac{1}{1 + 1/(F \tanh(T)\, e^{(1 - 1/F)T})}$$

where,

P = fraction of market captured (annual market for new applications and cumulative market for retrofits)

$T = ((T-T_o)/Y)^2$

T = year projection desired

T_o = year in which technology first becomes generally available (based on sales)

Y = time scale factor representing the number of years for the market to mature

Solar Heating and the Oil, Gas and Electricity Industries, P. 56.

APPENDIX A-5: METREK MARKET SHARE FUNCTION

Competition Among Backup Fuels

A consumer who decides to have solar energy in a new home must choose between several fuels available as backup for the solar portion of the heating system. Four potential backup fuels were identified: oil, gas, electricity (the three "conventional" fuels) and wood. Gas and wood are not, of course, valid options in all parts of the country because of limitations on their availability (see Chapter 3.3.3).

Where a choice of backup is possible, relative attractiveness was determined by the ratio of the inverse life cycle costs. For example, the projected market shares for each of the eight solar designs with oil backup is given by equation (2).

$$\frac{P_O}{P} = \frac{(1/LCC_O)}{(1/LCC_O + 1/LCC_G + 1/LCC_E + 1/LCC_W)} \qquad (2)$$

where:

P_O = the market share for a specific solar design with oil backup

P = total market for the solar design, independent of backup type

LCC_B = life cycle cost of the solar design with backup fuel (B) (oil, gas, electricity and wood)

The market shares derived with equation (2) were used as weights to estimate a representative or 'composite' life cycle cost for each of the eight solar designs independent of backup type, as shown in equation (3).

Source: Solar Heating and the Oil, Gas and Electricity Industries, (Energy, Mines and Resources Canada, Ottawa, 1979), P. 60-63.

The following describes the manner in which the market for solar space and water heating was distributed among the various design options.

<u>System Size</u> (i.e. SF1 versus SF2, and MF1 versus MF2 versus MF3)

The relative penetration or market share of two (or more) solar designs of different sizes was assumed to be inversely proportional to the composite life cycle cost (i.e. including backup costs) of the options (e.g., SF1 and SF2) in the way shown in 5.2.3.1. If the two life cycle costs are LCC_1, and LCC_2 then the relative market shares are proportional to $1/LCC_1$ and $1/LCC_2$. If these two solar designs are the only two available then the solar market would be divided into the fractions F_1 and F_2 according to equations (4) and (5).

$$F_1 = \frac{1/LCC_1}{(1/LCC_1) + (1/LCC_2)} \tag{4}$$

$$F_2 = \frac{1/LCC_2}{(1/LCC_1) + (1/LCC_2)} \tag{5}$$

where:

F_1 = the market share for solar systems of design SFi (i = 1,2)

LCC_1 = the composite life cycle cost* of SFi independent of backup type

*Calculated from equation (3) for each solar design.

$$LCC_{comp,N} = LCC_O \times \frac{P}{P_O} + LCC_G \times \frac{P}{P_G} \times LCC_E \times \frac{P}{P_E} + LCC_W \times \frac{P}{P_W} \qquad (3)$$

where:

$LCC_{comp,\ N}$ = composite life cycle cost of the solar design independent of backup fuel (N = SF1, SF2, MU, SFW, MF1, MF2, MF3, MFW)

In the case of retrofitted water systems or where the choice of backup is limited there was a slight deviation from this procedure. For retrofitted solar domestic water heating, the expectation is that there will be a tendency for owners more often to opt for a backup fuel which is identical to the original fuel used for conventional heating. This is not so in all cases since many homeowners may be prepared to change heating fuels. In order to approximate this phenomenon, a market preference of 25% for the same backup fuel was assumed. For example, if market shares were divided amongst three backup fuels by equation (2) as .33, .33 and .33, the adjusted shares would be .42, .29 and .29, the preferred fuel gaining 42% of the defined market. These modified market shares were then used to obtain the composite life cycle cost independent of backup type.

The second variation in the method resulted from the physical limitations to backup fuel availability. This was discussed in Chapter 3, and the assumed availability of each fuel for backup is shown in Table 3.2. To adjust for this consideration, the backup availability factors in Table 3.2 were multiplied by the market shares to yeild a revised market share consistent with the regional availability of alternative fuels.

5.2.3.2 Competition Among Design Options

The second type of competition among solar technologies results from the design variations possible for a given application. For multiple family buildings there are three choices of system size with a consequent range in the solar fraction. For single family dwellings, there are two system sizes for short term systems as well as a seasonal storage option, (the mini-utility) incorporating a different ratio of collector area to storage volume.

The market shares from equations (4) and (5) were used as weights to estimate a new composite life cycle cost (in similar fashion to equation (3)) for single family space and water heating systems (excluding the mini-utility system), and for multi-family space and water heating systems independent of system size and backup type.

An equivalent approach was used to estimate a composite life cycle cost for solar space and water heating in multi-family dwellings.

Storage/Collector Ratio (i.e. SF1 and SF2 versus MU)

In the previous sections relative market shares of solar systems with different designs for the same application were estimated using the inverse of the life cycle costs. This approach is consistent with the METREK market share function but only for technologies that enter the market at the same time. In the present study the mini-utility system was assumed to become commercially available some years after the individual systems. (See Appendix K for details.) Therefore, it was necessary to make separate projections of the market shares for the composite single family space and water heating systems and the mini-utility system, both independent of backup type. These market shares, derived separately for penetration into the oil, gas and electricity markets, were used in equations (6) and (7) to arrive at relative market shares for systems with different collector to storage ratios.

$$F_{MU} = \frac{P_{MU}}{P_{MU} + P_{SF}} \tag{6}$$

$$F_{SF} = \frac{P_{SF}}{P_{MU} + P_{SF}} \tag{7}$$

where:

F_i = relative market share for system is (i = MU, SF (composite of SF1 and SF2))

BIBLIOGRAPHY

American Planning Association, Site Planning for Solar Access, D. Erley et al., U.S. Government Printing Office, Washington, D.C., May 1980.

Anderson, B; Riordan, M., The Solar Home Book: Heating, Cooling and Designing with the Sun, Cheshire Books, Harrisville, N.H., 1976.

Antolini, H.L., Sunset's Homeowners Guide to Solar Heating, Lane Publishing Co., Menlo Park, Ca., 1978.

Argue, R., Renewable Energy Resources: A Guide to the Literature, Energy, Mines and Resources Canada, Renewable Energy Resources Branch, 1977.

Barnaby, C.S.; Caesar, P.; Wilcox, B., Solar for Your Present Home, Berkeley Solar Group, Berkeley, Ca., 1977 (prepared for California Energy Commission).

Berkowitz, M.K., Implementing Solar Energy Technology in Canada: The Costs, Benefits, and Role of Government, Energy, Mines and Resources Canada, Renewable Energy Resources Branch, 1978. (U. of Toronto, Institute of Policy Analysis).

Central Mortgage and Housing Corporation, The Conservation of Energy in Housing, Ottawa, 1977.

City of Winnipeg, Housing and Neighbourhood Strategies, Department of Environmental Planning, August 1979.

Comstat Consulting Service Ltd., New Energy/New Opportunities: Programs to Develop Renewable Energy and Conservation, Energy, Mines and Resources Canada, Conservation and Renewable Energy Branch, Ottawa, 1979.

Duffie, J.; Beckman, W., Solar Energy Thermal Processes, John Wiley & Sons Inc., New York, 1974.

Energy, Mines and Resources Canada, Energy Policy Analysis Division, Energy Demand Projections: A Total Energy Approach, Ottawa, 1977.

Energy, Mines and Resources Canada, Energy Policy Sector, An Energy Strategy for Canada: Policies for Self-Reliance, Ottawa, 1977.

Energy, Mines and Resources Canada, Oil and Natural Gas Resources of Canada: 1976, Ottawa, 1977.

Energy, Mines and Resources Canada, Energy Conservation in Canada: Programs and Perspectives, Ottawa, 1977.

Energy, Mines & Resources Canada, The National Energy Program, Ottawa, 1980.

Glover, M., ed., Solar Heating Catalogue No. 2., Energy, Mines and Resources Canada, Conservation & Renewable Energy Branch, Ottawa, 1978.

Gough, B.D., Passive Solar Heating: A Discussion Paper, Energy, Mines and Resources Canada, Conservation & Renewable Energy Branch, Ottawa, 1980.

Grignon, A., Solar Energy Project: SEP Note No. 1., National Research Council of Canada, Solar Energy Program, Ottawa, 1979.

Harrison, D., et al, The Local Government Role in Energy Policy, Harvard University Press, Cambridge, Mass., 1979.

IBI Group, Residential Solar Retrofit in Canada, Energy, Mines and Resources Canada, Conservation & Renewable Energy Branch, Ottawa, 1979.

Kadulski, R.; Lyster, T.; Richardson, J., Solpan 3: Solar Greenhouses for Canada, Drawing-Room Graphic Services, North Vancouver, B.C., 1978.

Lanczi, T., Assessment of Four Solar Domestic Hot Water Systems, Middleton Associates, for Ministry of Energy, Province of Ontario, Toronto, 1980.

Lorriman, D., Solar Technical Series No. 1: An Assessment of Problems Experienced with Operating Solar Systems in Canada and the Northern U.S., Moriyama Architects & Planners, for National Research Council of Canada, Toronto, 1978.

Marler, Blaine G., "Solar Energy: Applied to Rural Housing," Home and Community Design Branch, Alberta Agriculture, Edmonton, 1977.

Mazria, E., The Passive Solar Energy Book: A Complete Guide to Passive Solar Home, Greenhouse and Building Design, Rodale Press, Emmaus, Pa., 1979.

McCallum, B., Environmentally Appropriate Technology: Developing Technologies for a Conserver Society in Canada, Environment Canada, Office of the Science Advisor, Ottawa, 1977.

Mohammed, A., Energy Efficient Housing Design, Department of City Planning, University of Manitoba, Winnipeg, 1980.

National Energy Board of Canada, Energy Supply and Demand in Canada & Export Demand for Canadian Energy: 1966 to 1990, Ottawa, 1969.

National Solar Heating and Cooling Information Centre, Solar Hot Water and Your Home, Rockville, Maryland, 1979.

Province of British Columbia, Solar Energy, B.C. Hydro Energy Services Division, 1978.

Province of British Columbia, Recommendations for Solar Installations, B.C. Hydro Energy Conservation Division, 1978.

Province of Ontario, Builders' Guide to Energy Efficiency in New Housing, Ministry of Energy/HUDAC, Toronto, 1980.

Province of Ontario, Subdivisions and Sun: 3 Design Studies, Ministry of Energy, Toronto, 1979.

Province of Ontario, Turn on the Sun, Ministry of Energy, Toronto, October 1978.

Province of Ontario, Ontario's Energy Future, Ministry of Energy, Toronto, 1977.

Province of Ontario, Ontario Residential and Commercial Energy Demand Study, Informetrica Ltd., & Energy Research Group, Carleton University, for Ministry of Energy, Toronto, 1978.

Robertson, E.E., "Solar Energy Success Stories: A Summary of Current Economically Viable Applications of Direct and Indirect Solar Energy," Solar Energy Update '77, SESCI Confernce, Edmonton, August 1977.

Royal Architectural Institute of Canada, "Solar Energy Technology," Energy Conservation Handbook, Ottawa, 1978.

Sasaki, J.R., An Update to the Federal Solar Heating Program, Building Research Note No. 122, National Research Council of Canada, Ottawa, 1977.

Sasaki, J.R., Solar Heating Systems for Canadian Buildings, Building Research Note No. 194, National Research Council of Canada, Ottawa, 1977.

Scanada Consultants Ltd., Residential Renovation Potential in Canadian Settlements: Halifax Pilot Study, Canada Mortgage & Housing Corporation, Ottawa, 1979.

Scanada Consultants Ltd., Heating Canadian Houses: Current Performance and Potential for Improvement, Canada Mortgage & Housing Corporation, Ottawa, 1979.

Scanada Consultants Ltd., Physical Amenability of Canadian Housing Stock to Solar Retrofit, Canada Mortgage & Housing Corporation, Ottawa, 1979.

SESCI, Solar Energy Update '77, Solar Energy Society of Canada, Annual Meeting and Conference, Edmonton, Alberta, 1977.

SESCI, Solar Energy: Bringing it Down to Earth, SESCI National Conference, Charlottetown, PEI, 1979.

SESCI, Solwest '80: Forging the Solar Transition, SESCI & Pacific Northwest Solar Energy Association, Joint Solar Conference Proceedings, Vancouver, B.C., 1980.

Sewell, W.R.D., Accelerating the Acceptance of Solar Heating, Energy, Mines & Resources Canada, Ottawa, 1979.

Shillington, T., A Solar Energy Subdivision: An Assessment of Selected Institutional Barriers to Solar Energy in Winnipeg, Natural Resource Institute, University of Manitoba, Winnipeg, April 1979.

University of Saskatchewan, Energy-Efficient Housing - A Prairie Approach, Department of Mechanical Engineering, Energy Research Development Group, January 1981.

U.S. Department of Housing & Urban Development, Selling the Solar Home: Some Preliminary Findings, HUD Solar Demonstration Program, Washington, D.C., 1979.

U.S. Department of Housing & Urban Development, Davis Energy Conservation Report: Practical Use of the Sun, Washington, D.C., April 1977.

U.S. Energy Research & Development Administration, Solar Energy in America's Future: A Preliminary Assessment, Division of Solar Energy, Environmental & Resource Studies Branch, Washington, D.C., 1977.

U.S. Energy Research & Development Administration, National Program for Solar Heating and Cooling of Buildings, Division of Solar Energy, Washington, D.C., 1976.

U.S. Federal Energy Administration, Solar Energy: Project Independence, Inter-Agency Task Force on Solar Energy, Washington, D.C., 1974.

Victor, P.A., Solar Heating and the Oil, Gas and Electricity Industries, Middleton Associates, for Energy, Mines & Resources Canada, Conservation & Renewable Energy Branch, Toronto, 1979.

Wiggins, E.J., Prospects for Solar and Wind Utilization in Alberta, Energy and Natural Resource, Province of Alberta, Edmonton, Alberta, 1978.

Winnipeg Development Plan Review, Energy: A Background Paper on the Energy Crisis and the City of Winnipeg, Hildebrandt-Young & Associates, Winnipeg, Manitoba, 1978.

PERIODICALS

Canadian:

Canadian Renewable Energy News

SOL, Solar Energy Society of Canada (SESCI)

U.S.:

Solar Age

Solar Energy Update (HUD)

Solar Engineering

Solar Energy, International Solar Energy Society (ISES)

Solar Energy Digest

Solar Fact Sheet, National Solar Heating & Cooling Information Centre

Solar Energy Intelligence Report

Solar Law Report, Solar Energy Research Institute (SEEI)

Popular Science

Popular Mechanics

Mechanix Illustrated