solar technologies

To get a better idea of how solar technologies function, each one is described briefly and a sketch is included if appropriate.

Flat-Plate Solar Collectors

Figure 8 shows a schematic of a typical flat-plate solar collector. This is the most common type of solar collector used today in "active" solar energy systems. Flat-plate collectors convert solar radiation to heat energy. They consist of a flat absorbing surface with several parallel paths running lengthwise through it. A fluid is pumped through the collector. Sunlight heats the absorbing surface that conducts heat to the fluid. Some flat-plate collectors use air or another gas, others use liquid as the working fluid.

Flat plates can accept direct or indirect light from a wide range of angles. The absorbing surface is usually made of a material that is a good conductor of heat (like copper or aluminum). The flat plate is painted or chemically etched black to absorb as much solar radiation as possible. As the absorber warms, it transfers heat to the fluid within the collector but it also loses heat to its surroundings. To minimize this loss of heat, the bottom and

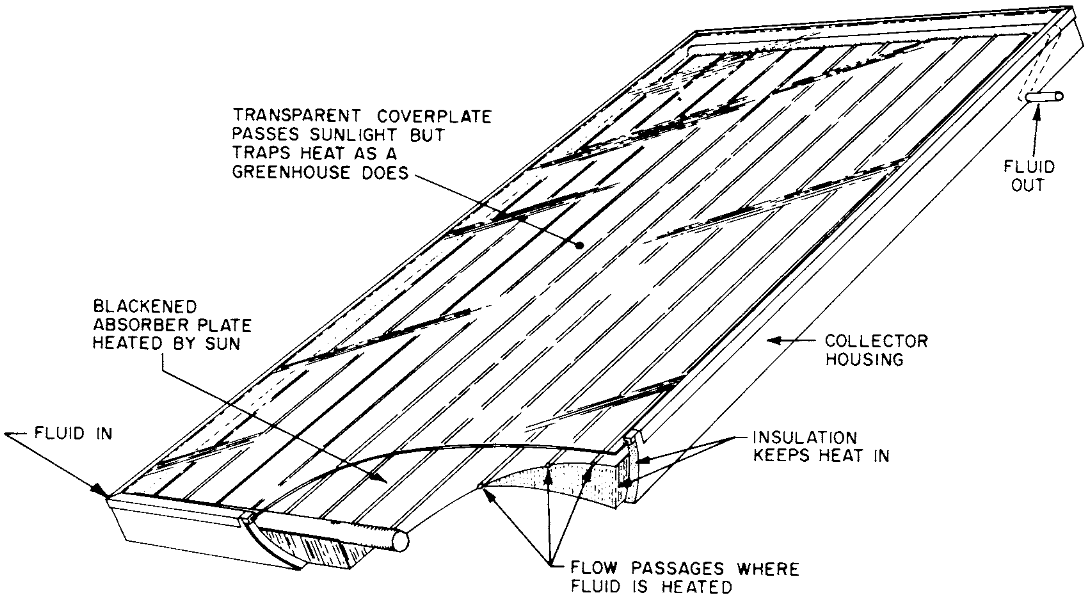

Figure 8. Schematic view of a typical flat-plate solar collector. Solar radiation (primarily visible wavelengths) strikes the surface of the glazings and is transmitted through them with a loss of 10 to 13 percent for each layer of glazing (only one glazing is illustrated). About 95 percent of the solar radiation striking the blackened collector plate is absorbed. This surface reradiates energy in the form of infrared radiation, which is trapped between the glazings and the absorber plate; this causes the collector plate to get hot. The collector fluid (liquid or air) is pumped through the collector to move the heat to where it is needed.

sides of a flat-plate collector are insulated, and a glass or plastic cover is placed above the absorber with an air space between the two. The cover permits the light to come through but reduces the amount of heat escaping.

For year-round use, a liquid-type collector must incorporate antifreeze for external circulation and a heat exchange loop to prevent the antifreeze from contaminating the potable water supply in the event of a leak. Liquid-type collectors also function in diffuse light, which is dominant on cloudy days.

Active systems employing flat-plate solar collectors are the most common type used to retrofit homes and businesses, due to the greater installation options.

Heat Transfer Fluids For Solar Heating Systems

Heat transfer fluids carry heat from solar heat collectors to the heat storage tanks in solar heating (and cooling) systems. The fluids most commonly used are water, propylene glycol, ethylene glycol, and air. Less common fluids are synthetic hydrocarbons, paraffin hydrocarbons, aromatic refined mineral oils, refrigerants, and silicones.

When selecting a transfer fluid, you should consider the following criteria: the coefficient of expansion, viscosity, thermal capacity, freezing point, boiling point, and flash point. For example, in a cold climate, solar systems require fluids with low freezing points. Fluids exposed to high temperatures, as in a desert climate, should have a high boiling point. Viscosity and thermal capacity determine the amount of pumping energy required. A fluid with low viscosity and high specific heat is easier to pump, because it is less resistant to flow and transfers more heat. Other properties that help determine the effectiveness of a fluid are its corrosiveness and stability. The following are some of the most commonly used heat transfer fluids and their properties.

Air will not freeze or boil, and is noncorrosive. However, it has a very low heat capacity and tends to leak out of collectors, ducts, and dampers.

Water is nontoxic and inexpensive. It has a high specific heat and a very low viscosity, making it easy to pump. Unfortunately, water has a relatively low boiling point and a high freezing point. It can also be corrosive if the pH (acidity/alkalinity level) is not maintained at a neutral level. Water with a high mineral content (i.e., "hard" water) can cause mineral deposits to form in collector tubing and system plumbing.

Glycol/water mixtures have a 50/50 or 60/40 glycol-to-water ratio. Ethylene and propylene glycol are "antifreezes." Ethylene glycol is extremely toxic and should only be used in a double-walled, closed-loop system. You can use food-grade propylene glycol/water mixtures in a single-walled heat exchanger, as long as the mixture has been certified as nontoxic. Make sure that no toxic dyes or inhibitors have been added to it. Most glycols deteriorate at very high temperatures. You must check the pH value, freezing point, and concentration of inhibitors annually to determine whether the mixture needs any adjustments or replacements to maintain its stability and effectiveness.

Hydrocarbon oils have a higher viscosity and lower specific heat than water. They require more energy to pump. These oils are relatively inexpensive and have a low freezing point. The basic categories of hydrocarbon oils are synthetic hydrocarbons, paraffin hydrocarbons, and aromatic refined mineral oils. Synthetic hydrocarbons are relatively nontoxic and require little maintenance. Paraffin hydrocarbons have a wider temperature range between freezing and boiling points than water, but they are toxic and require a double-walled, closed-loop heat exchanger. Aromatic oils are the least viscous of the hydrocarbon oils.

Refrigerants/phase change fluids, of which there are different kinds, are commonly used as the heat transfer fluid in refrigerators, air conditioners, and heat pumps. They generally have a low boiling point and a high heat capacity. This enables a small amount of the refrigerant to transfer a large amount of heat very efficiently. Refrigerants respond quickly to solar heat, making them more effective on cloudy days than other transfer fluids. Heat absorption occurs when the refrigerant boils (changes phase from liquid to gas) in the solar collector. Release of the collected heat takes place when the now-gaseous refrigerant condenses to a liquid again in a heat exchanger or condenser. For years chlorofluorocarbon (CFC) refrigerants, such as freon, were the primary fluids used by refrigerator, air-conditioner, and heat pump manufacturers because they are nonflammable, low in toxicity, stable, noncorrosive, and do not freeze. However, due to the negative effect that CFCs have on the earth's ozone layer, CFC production is being phased out —as is the production of hydrochlorofluorocarbons (HCFC). The few companies that produced refrigerant-charged solar systems have either stopped manufacturing the systems entirely or are currently seeking alternative refrigerants. Some companies have investigated methyl alcohol as a replacement for refrigerants.

If you currently own a refrigerant-charged solar system and it needs servicing, you should contact your local solar or refrigeration service professional. Since July 1, 1992, intentional venting of CFCs and HCFCs during service and maintenance, or disposal of the equipment containing these compounds, is illegal and punishable by stiff fines. Although production of CFCs ceased in the U.S. in 1996, a licensed refrigeration technician can still service your system. You may wish to contact your service professional to discuss the possible replacement of the CFC refrigerant with methyl alcohol or some other heat transfer fluid.

Ammonia can also be used as a refrigerant. It is commonly used in industrial applications. Due to safety considerations it is not used in residential systems. The refrigerants can be aqueous ammonia or a calcium chloride/ammonia mixture.

Silicones have a very low freezing point and a very high boiling point. They are noncorrosive and long lasting. Because silicones have a high viscosity and low heat capacities, they require more energy to pump. Silicones also leak easily, even through microscopic holes in a solar loop.

Evacuated Tubular Collectors

When adapting collectors for arctic conditions, it is an advantage if the collector design can utilize solar radiation from all directions. Due to low ambient temperatures it is also an advantage if the collector has a low heat loss so that as little as possible of the absorbed solar radiation is lost to the surroundings. Further, the collector must be able to utilize ground-reflected radiation, as the snow on the ground has a large reflection coefficient. Evacuated tubular collectors can be designed to fulfil these demands. There now exist two types of evacuated tubular collectors:

Heat pipe evacuated tubular collectors consist of cylindrical evacuated glass tubes which are connected to a condenser/heat exchanger unit. Inside the evacuated tubes are the absorber fins with selective coatings on the surfaces and with a heat pipe, which contains the working fluid, for example water. The working fluid evaporates at a low temperature when the absorber is heated by the solar radiation. The evaporated fluid rises in the pipe and condenses on the condenser in the heat exchanger unit. Thus the energy is transferred to the solar collected fluid, which is pumped through the condenser/heat exchanger unit. When the working fluid in the heat pipe condenses, it drops down in the heat pipe again and the whole process is repeated if the temperature is high enough. Figure 9 shows an evacuated glass tube with a heat pipe.

Figure 9. An evacuated glass tube with a heat pipe.

All-glass evacuated tubular collectors are designed in a different way. They are based on double glass tubes (see Fig. 10) with the evacuated space between the glass tubes. The outside of the inner glass wall is treated with an absorbing selective coating and works as the absorber. With solar irradiation on the tube, the inner glass tube gets very hot. The heat can be transferred from the inner glass tube to the solar collector fluid in different ways: Either the solar collector fluid is flowing directly inside the inner glass tube or the solar collector fluid can flow in a metal pipe, which is in good thermal contact with the inner glass tube.

Evacuated tubular collectors are suitable for arctic conditions because:

Figure 10. A double glass tube.

- The collectors have a low heat loss coefficient. The evacuated space in both types of evacuated tubular collectors limits the heat loss due to convection and conduction. Therefore, the heat loss from evacuated tubular collectors is lower than the heat loss from traditional flat-plate collectors.
- The collectors can utilize solar radiation from all directions. All-glass evacuated tubular collectors have cylindrical absorbers, and in eat pipe evacuated tubular collectors the absorber fin can have a curved shape, which follows the shape of the glass tube.
- The curved/cylindrical absorber shape can utilize the ground- reflected radiation better, as it can receive from nearly 360° around itself.

Passive Solar Space Heating

The House as a Solar Collector

Every surface of a building that is directly exposed to the sun's rays is collecting solar energy. Other surfaces, not directly exposed to the sun's rays, can be heated by convection, conduction, and radiation. The passive solar house maximizes this collection by:

- **Siting considerations.** During the heating season, the sun's path makes an arc in the southern sky. When designing and constructing a passive solar house, the consumer should be aware of the placement of trees, other houses, and mountains that might stand between the house and the sun's path in the sky. These objects may create shadows on a building and reduce the solar collection for that section of the house.
- **House orientation and shape.** South sides of houses receive the most solar radiation during the winter. East and west sides receive more solar radiation in summer than in winter. When designing a passive solar house, make the south side of the house longer than the east/west side.
- **Window placement.** South-facing glass windows allow direct sunlight to heat the interior of the house. In

an energy-efficient house, south-facing windows can provide up to 30 percent or more of the heating load. An overhanging eave or awning on south-facing windows will prevent overheating during the summertime. Also, too much glass on the west side of the house can easily overheat rooms that have already been warmed all day by the southern sun.

- **Glass design.** Maximize the R-value of windows without inhibiting visibility. New low emissivity glass will decrease radiant heat loss and increase R-value without markedly lowering visibility. Improved glazings are in constant development and emerge on the market regularly.
- **House color.** Dark colors absorb more sun energy than light colors do. Light interiors reflect more light and reduce lighting needs.
- **Solar greenhouse.** When attached to a south wall, a solar greenhouse provides additional collector area as well as space for houseplants and food production in winter months.

Storing Passively Gained Solar Heat—Not an Alaska Strategy

The usual rule of thumb about passive solar design routinely includes an indexed amount of what is termed "Thermal Mass" in the home. This typically is accommodated by designing the solar gain space with a large amount of concrete masonry or other massive building material to store the solar heat during the day and release it (theoretically) back to the living space at night when the sun has set. But is this an economical strategy for Alaska? The answer is generally no! Why is this?

The rule of thumb for passive solar design that recommends one cubic foot of concrete for every square foot of solar aperture area was developed in the southern and southwestern U.S. where substantially more solar gain is to be had during the winter heating months than in Alaska. This thermal mass question needed to be tested with research, so in 1983–1984, Richard Seifert conducted a study of the effects of thermal storage mass for the heating of a test building in Fairbanks, at the University of Alaska. The conclusions from this testing indicate that it is not really feasible to size a mass system such that it can function well for any significant portion of the year. What happens is that for the major portion of the heating season (from mid-November to mid-February) the mass is of no practical use. Even during the best solar heating season of the year (March and April), the storage was useful on only 22 of 57 days (38 percent). The conclusion is that sizing a storage system to moderate overheating and store useful heat for later release is, at subarctic latitudes, of very limited use. And there is the additional factor of high cost for inclusion of thermal storage in a building, so it is difficult to recommend this strategy for Alaskans. For the most effective use of passive solar heating, we suggest south glazing with a thermally efficient building envelope. Keep the mass to a minimum in the house, and ventilate when overheating occurs. This means solar gain is an economical source of opportunity, but not worth it to the average homeowner (at this time) to provide for its short-term storage.

The House as a Heat Trap

Passive solar heating goes hand in hand with good building, insulation, and conservation practices. High heat loss through walls, ceilings, and windows increases both the area required for solar energy collection and the amount of additional energy source needed (Figure 11).

The recommended insulation values for a passive solar house in Alaska are R-38 walls and R-50 ceilings. However, any increased insulation will increase the solar performance.

R-38 walls and R-50 roofs, along with proper sizing and placement of windows can cut fuel bills by 50 percent and up.

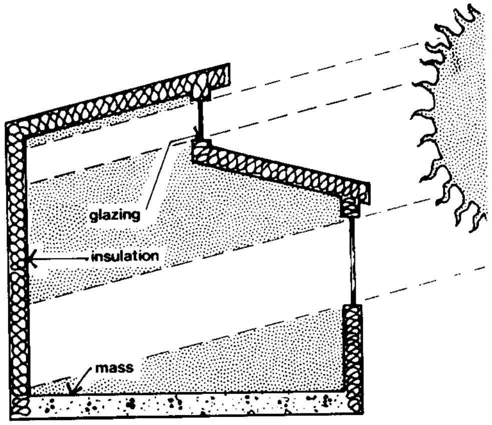

Figure 11. Passive solar heating employs the entire structure as the solar collector and the thermal storage medium.

Single-pane windows lose three times as much heat as triple pane and forty times as much as an R-38 wall. Insulated shutters should be used to reduce nighttime heat loss. There are also a number of new glazings on the market, such as low emissivity "Heat Mirror."® These increase the insulating effect of glass and make the house more comfortable.

Heat Gain Through Glazing

The most widely used form of solar heating is sunlight entering a building directly through windows. This provides light (displacing artificial lighting) and eventually ends up as heat after striking objects in the room.

Heat Loss Through Glazing

To effectively reduce heat loss through windows, at least two layers of glass are needed in cold climates. A third layer of glass can reduce heat loss further. The best way to reduce such heat loss is to cover the windows with insulation during periods when there is no direct or indirect sunlight available. This movable insulation is also called a thermal shutter or night insulation.

The use of thermal shutters can often be forgone in the warmer climates of the Lower 48, because there is enough solar gain available during the day (usually) to offset the high heat loss from uninsulated glazing at night. However, to obtain the best performance on an annual basis in Alaska, thermal shutters are imperative. A small net gain in heating can be obtained from triple-glazed south-facing windows in many Alaska locations. But this gain is insignificant compared to the 25 to 40 percent heating load reduction that can be provided in some parts of the state by the creative use of south-facing glazing that is covered with R-9 shuttering during periods without solar gain.

The real problem of shuttering is the lack of a mature technology. Although many variations of mechanical and automatic shutters exist, none could truly serve all broad-ranging Alaska applications adequately. Several options for night insulation are discussed further in the passive design section.

Economics

Depending on the type of system used, the builder's familiarity with the concept, and more important, the small details of passive solar design and construction, passive solar features can add 0 to 15 percent to design and construction costs. However, this is a one-time cost for energy saving features that last the lifetime of the building. Many features such as proper siting, house color, house orientation and shape, and window placement can be considered without additional costs. Passive solar heating can pay for itself within five to seven years in Alaska, except in areas where energy is very cheap. Use of computer-aided design and new windows can minimize the extra cost of solar design.

Passive solar heating requires the occupant to become more aware of the surrounding environment.

Passive solar heating is gaining market acceptability. In Alaska, passive solar houses have been built in Anchorage, Homer, Juneau, Delta Junction, Copper Center, Ambler, and Fairbanks, among others.

Passive solar heating provides space heat that is inherently simple, clean, safe, cheap, and lasts the lifetime of the building.

Energy Storage

Storage technologies include seasonal thermal storage, diurnal (daily) thermal storage, battery storage of electricity, and storage of hydrogen.

The element of energy storage appears again and again in the application of renewable energy sources. It is a pressing technological problem that limits the optimum use of solar, wind, and photovoltaic energy. A sophisticated, inexpensive, and reliable energy storage system would overcome many of the physical barriers to using renewable energy resources. Solar seasonal storage systems for space heating are not yet practical. Using water to store 25 million BTU for heating during the four coldest months in Alaska (November, December, January, and February) would require about 8,012 cubic feet of storage, a volume equal to 31×31×8 ft, a little larger than a common basement. The 25 million BTU would only be adequate if the building were superinsulated (an integrated R-value of about 25). Standard houses older than fifteen years often require 120 to 150 million BTU of heat annually, 60 percent of which is required during the four coldest months.

The problem is clear. Both thermal and electrical storage systems and storage efficiencies need to be improved since each would greatly improve the usefulness, cost, and reliability of renewable energy resources.

Water and Water Tanks

Water is not only an inexpensive heat storage medium, it also has the highest heat capacity per pound of any ordinary material (1 BTU/lb °F). Although other liquids may be used to transfer heat from the collector, the storage tank generally contains potable water (for domestic water heating systems), or corrosion-inhibited water with antifreeze (for space heating systems). For a residential space heating system, one day's storage requirement is about 1 to 2½ gallons per square foot of collector. Water is commonly used for an active system storage, but it can also be used in passive systems in the form of large tanks, waterwalls, and other containers of water, which are placed in a sunlit area to gain and store heat.

Rocks and Rock Bins

Rocks are used with air heating collectors rather than with liquid collectors. Hot air is blown into a rock storage bin, which should contain about 1 cubic foot per square foot of collector. This is about 2½ to 3 times the size of a water storage tank for the same size collector.

The bins used to store the rocks can be constructed inside the basement. Underground bins are not recommended. Water seepage can ruin insulation and in some cases can infiltrate the walls of the container. It is essential that the bin be constructed so that no water vapor, vermin, or insects can enter. All sides of the bin must be insulated.

Phase-change Materials and Containers

Phase-change materials store and release heat at a constant temperature by melting and freezing. As heat comes from the collectors to the storage, the material changes to liquid. Upon cooling, it changes back to a solid and releases heat that can be used to heat the home. The size of the storage bin need only be one-quarter to one-half the size of water storage for a comparable amount of collector area.

The phase-change media include: (1) disodium phosphate dodecahydrate, (2) sodium thiosulfate pentahydrate, (3) paraffin, and (4) sodium sulfate decahydrate (Glauber's salts). The performance of sodium sulfate degrades after several cycles of melting and solidifying. Its melting temperature, 89°F, is lower than the usual temperature used in forced-air heating systems, so increased airflow rates and larger ducts are needed.

Phase-change materials are most often contained in small tubes or trays, which are tightly sealed to prevent leakage, moisture transfer, and oxidation. The containers should be chemically compatible with the phase-change medium selected. A large number of these containers are needed to provide the large surface area needed for heat exchange. This makes phase-change storage more expensive than rock bins or water tanks.

Seasonal Storage

Further mention is made here of seasonal storage, which is a logical step to pursue in developing solar energy use in the far North. Since more than enough solar energy for normal heating needs occurs in the summer season, the need for a seasonal storage technology in Alaska is great. It is the best long-term approach to achieve 100 percent solar heating in the far North; this is feasible but not economic at present. In Sweden, long-term thermal storage is being built and tested at the neighborhood scale, which is more economic. In this conception, the storage tank is sized (several hundred thousand gallons) to supply heat for an entire block, and collectors are mounted atop the storage tank and collect the summer sun. Such solar development requires planning and land use that is not common in Alaska today. Perhaps these options will be more attractive as they become better known.

There are other major advantages. Annual storage is virtually immune to short-term weather variation. It is practical and economical to design for 100 percent solar heating for an average year. This compares to 30 to 35 percent solar, which is apparently the economic choice for short-term storage systems.

Since the cost of storage is more important with annual storage (it accounts for more than one-third of the total system's cost), larger installations have a major advantage. This is due to the squared-cube laws: as the size of storage increases, the surface area rises only as the square of the dimension while the volume increases as the cube of the dimension. Therefore, the cost of the storage—which depends mainly upon the surface area—decreases rapidly as the capacity increases.

It is to be expected that annual storage systems will be favored in high-latitude locations and that, initially, larger installations will show considerably greater advantage over smaller systems.

Because of the higher annual heat loads in the North, much higher investments in solar heating systems can be amortized than in more moderate climates. The cost of a solar heating system does not increase linearly with the capacity; therefore northern locations look particularly favorable, despite their somewhat lower annual average collector efficiencies caused by the lower ambient temperatures.

It is important and timely to ask about the prospect of zero net energy homes for cold climates. Is it possible? Practical? Even desirable? Here's what Canadian low-energy housing expert Rob Dumont (2005) has to say on this issue.

Rob first discusses the Danish Zero Energy House, which was the first "proof of concept" house of its type in the world. He then describes how one might approach design of a net zero energy house for a cold climate. Although his experience is from his home region, the Canadian province of Saskatchewan, his design approach is a very fine and feasible one for moving toward zero net energy homes for our even more challenging climatic areas in Alaska.

The Zero Energy House in Denmark

A super energy-efficient house (Korsgaard, 1977) was built in 1975 near Copenhagen in Denmark. Called the "Zero Energy House," this house was unique in that it was probably the first super-insulated house in the world. The house had approximately 300mm of mineral wool insulation in the walls and floor. This amount of insulation was approximately three times as large as that used on most houses at the time. It incorporated insulating shutters on the windows, one of the first air-to-air heat exchangers ever used on a domestic residence, and a solar heating system that was designed for 100% solar space and water heating. Despite some problems with air sealing of the envelope, and breakage of glass on the solar collectors, the house was able to achieve close to 100 percent space heating from the solar system. However, because of the large amount of water storage used (equal to 35 percent of the volume of the house), the solar heating system on the house did not become commercially attractive.

Figure 12. This is a photo of the "Null Energihuset" built at the Technical University of Denmark in 1975. It is the first house to attempt full seasonal solar heating through storage at a high latitude. Details are elaborated in the text. (Photo by author, April 2005.)

Is a Zero Energy House Possible in a Cold Climate?

A reasonable question to ask is whether it would be possible to extend conservation features and renewable energy features and build a house in a cold climate such as Saskatchewan that was completely autonomous in its energy supply.

Technically, it now is feasible. Here is an outline of how it might be done.

1. Water Heating.

The water heating load could be carried by a solar collector system coupled with water storage. An average house incorporating water saving features uses about 4000 kWh/yr (~13.6 million BTUs) for domestic water heating. A solar collector with 40 percent annual efficiency can collect about 550 kWh/m^2 of useful solar heat. Thus a collector of about 7 square meters, coupled with a large water storage, can provide the domestic water load.

2. Space Heating.

Space heating could be provided by using a highly energy efficient envelope for the building coupled with super-window technology. The solar collector system could be sized to provide the space heating that was not carried by the passive solar contribution. In effect, such a water and space heating system would resemble the 1977 Saskatchewan Conservation House approach. Advances in computer modelling, solar collection devices, storage and distribution technologies all appear to make such an approach feasible. On the Saskatchewan Conservation House, a total solar collector area of 17.8 m^2 (~200 ft^2) was used to provide both space and water heating.

3. Supply of electricity for lights and appliances.

The supply of electricity is the most expensive element, given today's technology. In a windy location in a rural area, a wind electric system could be used. In an urban area, it would appear that the use of photovoltaic cells would be the most attractive. In recent years, the price of cells has declined. Some preliminary calculations indicate that by using the best state-of-the-art energy efficient appliances and lights that the amount of electrical energy in a typical residence can be reduced to approximately 2000 kWh/yr, for a reduction of about 75 percent compared to conventional houses. A solar electric system able to provide that amount of electricity would have to be about 16m^2 in area on an assured basis year-round in a location such as Saskatoon (Saskatoon is at latitude ~52°N).

A legitimate question to ask is whether such an approach is economically attractive. However, a more fundamental question is "What is the real cost of energy?" In addition to the cost of extracting, processing, and delivering energy, there is the very substantial environmental cost, which today is not being paid. There is no charge to the consumer of energy for all the pollutants released into the atmosphere from the burning of fossil fuels. Carbon dioxide levels in the atmosphere are now 25 percent higher than a century ago, and are rising each year.

Almost all the energy used in Saskatchewan is fossil fuel based, and Saskatchewan (Lobbe, 1990) has a per capita release of 8.6 tonnes of carbon per person per year, or approximately 8 times the average per capita value for the world.

Were the real costs of energy to be paid, it is much more likely that autonomous houses would be feasible.

Figure 13. South side of the Saskatchewan Conservation House, 1977. Note the active solar panels (vacuum tube) on the upper part of the south wall, and the insulating shutters on the lower windows. An 11,000 liter water storage tank was incorporated to store solar heat within the house.