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Feasibility study on the use of solar energy for the heating of homes in central Montana

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A FEASIBILITY STUDY ON THE USE OF SOLAR ENERGY FOR THE HEATING OF HOMES IN CENTRAL MONTANA

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CHAPTER I

INTRODUCTION

Scope and Purpose

Power is the basis of our industrial civilization--rise of civilization is due to the ability to use power. Without an ample supply of power, our civilization would quickly come to a standstill. The rise in living standards in the United States in the past, especially in the last decade, has been due to our great ability to use energy. These days a good portion (nearly 21 percent) of the energy used in the United States is for space heating. Of this amount, 12 percent is used in the heating of our homes.[1] It is apparent, then, that in future years as the population increases, we will need even more power.

The need for energy in the future is so great that even if the efficiency of present fuels was greatly increased they would still supply only a small portion of the energy that will be needed. Total United States energy consumption will continue to rise, projected at a cumulative annual rate

[1]John C. Fisher, Energy Crisis in Perspective (New York: John Wiley & Sons, Inc., 1974), p. 5.

of about 4 1/2 percent over the next couple of decades.[2] This will mean that in twenty-four years the United States will need twice the amount of energy that is used today.

This great need for energy, coupled with the increased cost of energy--especially the cost of Middle East oil--has finally awakened us to the fact that we need to find alternative sources of energy to that provided by fossil fuels. Some of the better known sources include: geothermal energy, wind energy, solar energy, and nuclear fusion. Of all these, solar energy offers the greatest potential. It is nonpolluting, has minimal environmental consequences, and is an unending and nondepletable source of energy.

The purpose of this paper is to study solar energy and its application as a source of energy for the heating of homes. The paper starts with the definition of solar energy, followed by a brief history of its applications down through the years. The most recent uses of solar energy, including rooftop water heaters and the solar collectors used in the heating of homes, are also discussed.

The main portion of the paper explains a basic solar energy system with collector, storage, heat exchange and associated equipment, incorporating the most economical and efficient features for the average home. This system will then be compared to the conventional heating systems of electric

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[2] John L. Moore, ed., Continuing Energy Crisis in America (Washington, D.C.: Congressional Quarterly, Inc., 1975), p. 22.

heat and natural gas in order to determine its economic feasibility.

What is Solar Energy?

Our sun, being a star with a temperature approximately 6000 degress Kelvin, emits electromagnetic radiation of varying wave lengths and frequencies. These different wave lengths of radiation produced by the sun constitute the electromagnetic spectrum (Figure 1). This energy travels more than 93 million miles, at a speed of 186,000 miles per second, and obeys all the laws of reflection and refraction. The only difference among waves is their different wave lengths and frequency.[3]

However, not all the electromagnetic radiation reaches the earth's surface, mainly because the atmosphere, composed of many different substances, absorbs a lot of that energy. The three substances which absorb the most energy are: water vapor (H_2O), carbon dioxide (CO_2) and ozone (O_3). Carbon dioxide and ozone absorb energy in the upper portion of the atmosphere whereas water vapor is prevalent in the lower portion of the atmosphere.[4] With all of these different substances absorbing energy, it is clear why only a small portion of the energy reaches the earth's surface. Actually, there

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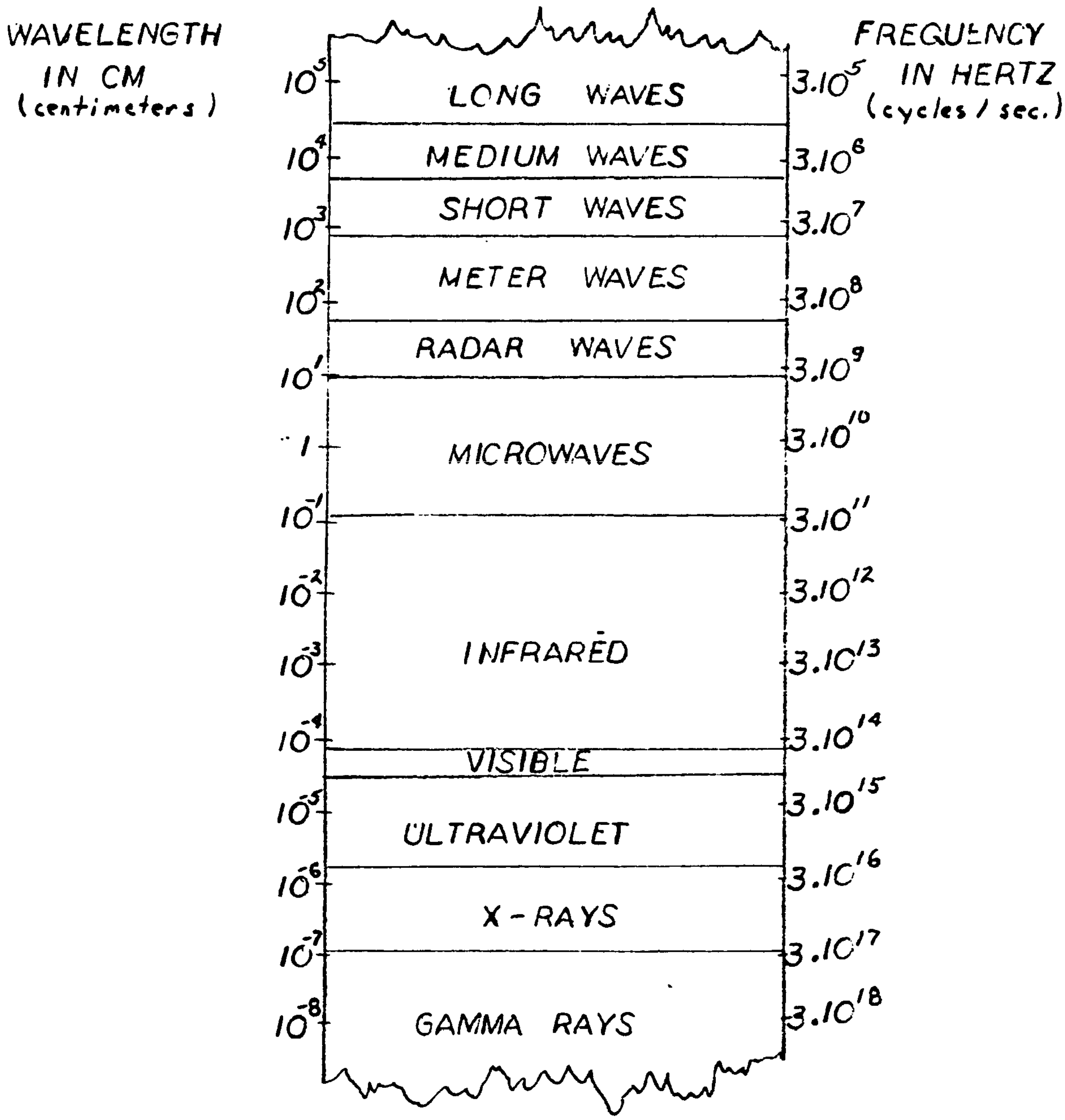
[3] Karl O. Kiepenheuer, The Sun (Ann Arbor: The University of Michigan Press, 1959), p. 138.

[4] Donald H. Menzel, Our Sun (Philadelphia: The Blakiston Co., 1950), p. 72.



ELECTROMAGNETIC SPECTRUM
FIGURE-1

are only two openings or "windows" (in the atmosphere) through which the wave lengths reach the earth. One is called the "visible window" and the other the "radio window."[5] Only the visible window is pertinent here because through it the earth's surface receives ultraviolet, infrared, and visible light waves of the electromagnetic spectrum. These three basic parts compose 4 percent, 16 percent, and 80 percent, respectively, of the energy reaching the earth's surface.[6]

Actually, the amount of energy the earth's surface receives from the sun can be considered infinite. As a planet, the earth receives only two-billionths of the energy that the sun produces.[7] Only half of this is received on the surface of the earth because the earth's atmosphere reflects the other half. This one-billionth of the sun's energy is equivalent to 10^{18} horsepower.[8] In watts, the energy falling on the earth in a year is about 1.72×10^{17} watts, a million times greater than all the electricity that was generated in the United States in 1959.[9] Alternatively, the energy received per acre each at the 25° latitude of the earth's

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[5]Raymond A. Wohlrabe, Exploring Solar Energy (New York: The World Publishing Co., 1966), p. 33.

[6]Franklyn M. Branley, Solar Energy (New York: Thomas Y. Crowell Co., 1957), p. 26.

[7]Menzel, Our Sun, pp. 290-91.

[8]Branley, Solar Energy, p. 29.

[9]M. King Hubbert, Energy Resources (Washington, D.C.: National Academy of Sciences, 1962), p. 58.

surface is equal to that contained in a thousand tons of coal.[10] To compare solar energy with other energy sources, in just one year the radiation reaching the surface of the United States exceeds the total amount of fossil energy that will ever be extracted in this country.[11] Because solar energy is the largest nondepletable source of energy the earth has, it is quite evident that mankind should attempt to harness it for use.

Past Use of Solar Energy

With a basic idea of what solar energy is and how much of it the earth receives, a look at some of the past uses of solar energy is in order. The earliest and best known discovery of the use of solar energy is that of Archimedes who used concentrated sunlight to set fire to the sails of Roman ships.[12] Naturally, the sun served as a weapon rather than a source of power in this case, but it shows that solar energy has been in the minds of man for thousands of years.

More recently, in the nineteenth century, men were working on a variety of ways to harness the sun's rays. A scientific paper on the sun and the welfare of man, published by the Smithsonian Institute in 1934, describes several.[13] To

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[10] Branley, Solar Energy, p. 37.

[11] Edmund Faltermayer, "Solar Energy is Here, But It's Not Yet Utopia," Fortune, February 1976, p. 103.

[12] "Archimedes' Weapon," Time, 26 November 1973, p. 60.

[13] Charles Greeley Abbot, ed., Smithsonian Scientific

de Saussure, a Swedish scientist, credit is given for inventing the "Hot Box" (i.e., an insulated air-tight wooden box, with black interior, and covered with two layers of plain glass with an air space between them), which has been a favorite with inventors ever since. He also discovered that two sheets of glass gave the best results. (This approach to collecting solar energy will be discussed more fully in Chapter 2.)

August Mouchot started his solar work in 1860. His first solar engine was made around 1866, he constructed his first sun boiler in 1872, and in 1878 he constructed a larger sun boiler with a capacity of 100 liters. Mouchot's basic boiler was made of copper with the umbrella dish coated with silver. The center of the boiler was a blackened copper cylinder covered by a bell glass. Inside the main cylinder was yet a smaller cylinder. Water was fed between the two cylinders, and, when heated, formed steam. The whole apparatus was inclined to approximately 45 degrees in order to get the maximum amount of rays on the cylinder.

About the same time, John Ericson was working on finding the solar constant (the amount of solar radiation reaching the earth's atmosphere). It is equivalent to 1.94 calories per square centimeter per minute, or 430 BTUs for each square foot per hour. He later made an apparatus for practical

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Series, 12 vols. (New York: Smithsonian Institution Series, Inc., 1934), vol. 2: The Sun and the Welfare of Man, pp. 195-204.

utilization of solar energy and is credited as the first person to build a steam engine driven by the direct use of solar radiation.

One of the first individuals to work on the practical side of the utilization of solar energy was W. Adams, an Englishman living in Bombay. He is believed to be the first to build a solar cooker. Again a copper cylinder was used, covered with an octagonal glass shade centered in the middle of an octagonal shaped umbrella.

M. Abel Pifre was one of the first to use a parabolic reflector (instead of a truncated cone), and thereby reduced the surface of the boiler, increasing the concentration of the sun's rays. He ran a printing press with his sun-powered plant in 1878.

J. Harding designed the first plant for distilling water by solar radiation. Located in Salinas, Chile, the plant yielded 5,000 gallons of pure water per day in the summer months, or one pound of water per square foot of glass.

Moving into the twentieth century, A. G. Eneas of Pasadena, California, built a reflector-type boiler in 1901. This was the largest and strongest of the mirror type of solar motors ever built in that area.[14]

More representative of the present day conversion of solar energy, H. E. Willsie and John Boyle, Jr., started their work in 1902. Their method allowed solar radiation to

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[14]Ibid., pp. 206-10.

pass through glass to heat water which was used to vaporize some volatile fluids like ammonium hydrate, ether, or sulphur dioxide: vapor which was used to drive an engine. Again, the basic collector was that of the hot box design by de Saussure, the only differences being the materials of construction and the fact that the bottom of the collector was filled with three inches of water.

Frank Shuman, of America, continued working in this area in 1906. Within a year he had a plant with a 1,200 square foot horizontal water box which contained rows of parallel black pipes containing ether. The water conveyed heat to the pipes, which caused the ether to boil, which, in turn, powered a single cylinder engine.

In 1910 Shuman constructed an experimental absorber measuring six feet by nine feet, again using the "hot box" principle. It also used no concentration of the sunshine by mirrors or reflectors. The highest temperature ever recorded in the box was 250°F. This was a very crude model of the basic flat-plate collector that is used today.

Even the "father of modern rocketry," Dr. R. H. Goddard, experimented with the use of solar energy. Realizing the need for an efficient means of storing energy for solar engines, Dr. Goddard applied for five patents covering this and his solar power plant.[15]

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[15] D. S. Halacy, Jr., The Coming Age of Solar Energy (New York: Harper & Row, Publishers, Inc., 1963), p. 213.

The next real practical use of solar energy was the solar water heaters. These heaters, which consisted of a glass plate collector containing a copper coil and a storage tank for holding the heated water, were in use in California and Florida in the 1930s.[16] By 1963, in Florida alone, an estimated 25,000 such units were in operation for the heating of swimming pools, homes, apartments, and even laundries.[17]

For years, people in Australia, Israel, Japan, and Latin America have used solar energy to heat their water simply by storing it in rooftop tanks.[18] Other countries, in particular Australia and Israel, have still more advanced solar water heaters mainly because solar heat research has been generously funded in these countries.[19] Yet still another recent use of solar energy is that of concentrating solar energy by mirrors onto a single point or area providing a solar furnace for simple industrial processes.[20]

Since solar water heaters have existed for years, it is not surprising that man has finally decided to try to heat his entire home with solar energy. The first solar houses were built in the United States in 1958-1959. They consisted

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[16]D. S. Halacy, Jr., Fun With the Sun (New York: The McMillian Co., 1959), p. 65.

[17]Halacy, The Coming Age of Solar Energy, p. 135.

[18]"Turning On the Sunpower," Newsweek, 16 July 1973, p. 78.

[19]Eliot Marshall, "Power From the Sun," The New Republic, 25 December 1973, p. 16.

[20]"Turning On the Sunpower," Newsweek, p. 78.

of a solar collector (hot box design) where the water is heated by the sun's rays, a storage area (a large water tank), and the necessary plumbing, including pump, switches and thermostats to operate the system. The two most famous houses were built by George Löf of Colorado and Harry Thomason of Washington, D.C. An example of Mr. Thomason's first house and heating system can be seen in Figure 4, Chapter 2. Mr. Thomason has built several such solar houses over the years. Not many of these experimental houses have survived; in fact, up to two and one-half years ago, there probably were only a dozen solar houses in the United States.[21]

Solar Energy Today

Since energy is becoming more expensive and a greater portion of energy (28 percent more from 1960 to 1968) is needed to heat our homes, it is clear that an analysis must be made of the feasibility of solar energy for heating homes.[22]

Probably the greatest drawback to the widespread use of solar energy for heating homes has been an economical conversion system. The technological aspects have been proven since 1958. However, in a capitalistic society the high cost of mass producing solar energy conversion systems has been holding up the use of such a system. Furthermore, consumers have not pressured for or requested solar heating to any extent because

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[21] Marshall, "Power From the Sun," p. 16.

[22] Fisher, Energy Crisis, p. 153.

they feel that it is still cheaper to use oil or gas to heat their homes. They may not be aware that the low cost abundant energy is gone. Also, since they have been using oil and gas for years, consumers are naturally reluctant to change. This reluctance to change is strengthened by the lack of general public awareness of the possibilities available.

One of the things that has seemed to boost solar energy conversion and public interest is that the federal government has taken the matter seriously. Along with former President Nixon's plan of "Project Independence," funds spent for solar research tripled to $3.96 million between 1972 and 1973, and they tripled again in 1974 to $13.2 million.[23] Currently the government has authorized $75 million in fiscal 1976 for solar energy research, and another $60 million over a five year period to develop solar heating and cooling for buildings.[24]

The government also acts as a catalyst by allowing tax write-offs and other inducements for the use of solar energy. An example of this is the California public utility commission decision to ban any new gas hookups for swimming pool heaters. In fact, an estimated four thousand swimming pool owners in the Southwest currently use solar energy to heat their pools because of the shortage of natural gas.[25]

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[23] Marshall, "Power From the Sun," p. 17.

[24] Moore, Continuing Energy Crisis, p. 107.

[25] "The New Business of Harvesting Sunbeams," Fortune, February 1976, p. 109.

The government also offers write-offs for solar heated homes.

Most of the new activity in solar heating is in new homes because of the high cost of converting existing homes. The collector must be positioned in relation to latitude, slope, and longitude in order to get the maximum amount of the sun's rays.

Some of the most recent developments include homes as far north as New Hampshire. The two best known specialists, Mr. Thomason and Dr. Löf, continue to be in the forefront of the solar home field. In fact, Mr. Thomason just finished designing a solar heating system that was so efficient that its owner Mr. Robert Homan used only thirty gallons of heating oil through December for space heating. In Denver, Dr. Löf helped design the first factory applications of solar energy. The installation at this factory has 1,600 square feet of rooftop collectors that supply about 90 percent of the heat needed for 7,200 square feet of office space below.[26]

Moving closer to home in Great Falls, Larry Truchot, an architect, is presently in the midst of building a solar-heated home. His system is very similar to that shown in Chapter 2, with only a few minor changes that he thought would improve its efficiency.

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[26]Ibid., p. 108.

It has been seen that there are quite a few solar heated homes in the United States. But still, the solar energy development business is small. The sales of the industry, including flat-plate collectors, water heaters (rooftop), solar cells (photovoltaic cells), and associated pumps, switches, thermostats, etc., has not exceeded $25 million a year.[27]

Besides the hundreds of inventors and entrepreneurs, there are many tiny enterprises, plus giant corporations. Some of the big companies involved in solar energy development are PPG, Revere, Reynolds Metal, Grumman, Owen-Illinois, and Lennox Industries. All of these presently make "flat-plate" collectors. However, they are fairly expensive for the average consumer. The high cost is due to the fact that demand has not been high enough for the companies to mass-produce the products. Also, the materials used in some collectors are not inexpensive. (An example of this is Revere, which uses copper in making their solar collectors.) No one disputes the heat transfer qualities of copper, but it is very expensive for use in the flat-plate collectors. Steel and aluminum alloys are the cheapest materials for such collectors.

The present work of inventors is to find the most economical and efficient solar heating system possible. Hopefully, mass production of such a system for the average

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[27]Ibid., p. 107.

homeowner's use will occur someday. One might say that solar energy systems are as well developed today as cars were before Henry Ford introduced the mass production line.

CHAPTER II

DETERMINATION OF AN OPTIMUM SOLAR ENERGY SYSTEM

Direct Conversion Methods

In determining an optimum system, one must analyze the direct conversion methods of converting the sun's rays into useable forms of energy. The direct conversion of sunlight into electricity is called the photovoltaic process (solar cells). The two other types of direct conversion (although not as direct) are thermoelectric and thermionic conversion. These two methods use the heat of the sun's rays to product electricity. (However, these methods must use more elaborate equipment, concentrators, to do so.) Since most of these systems were developed for the energy needs of the space program, they really are not readily adaptable to residential use. Only the photovoltaic method has been experimented with for residential use. However, it takes thousands of dollars' worth of solar cells in order to produce enough electricity to meet the demands of an average home.[1]

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[1]Len Buchwalter, "Solar Cells Come Down to Earth," Mechanix Illustrated, April 1976, p. 39.

With these methods for producing electricity being too costly and technologically unsound for residential use, the only alternative is the direct use of the sun's rays for heating by the use of a thermal energy collector. It is very similar to de Saussure's "Hot Box" and Shuman's experimental "Absorber" discussed in Chapter I.

Thermal Energy Collector

The basic collector is usually a rectangular-shaped box made out of wood. The face consists of two panes of low-iron tempered glass with an air space between them. The reason for the two panes of glass is to enhance the "greenhouse" effect by allowing minimal thermal losses. The "greenhouse effect" is the effect of light and infrared energy passing through the glass and being absorbed by the collector. The collector then radiates this energy back in the longer wave lengths of the infrared part of the spectrum (see Figure 1 in Chapter I). These longer waves cannot penetrate the glass.[2]

Beneath the panes of glass there is another larger air space before one reaches the base of the collector. This base is made out of a sheet of copper, aluminum alloy, or steel. It can be either a flat or corrugated sheet, and is painted with a flat, black paint or a selective coating like nickel black in order to enhance its absorption characteristics.

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[2]Wohlrabe, Solar Energy, p. 54.

Underneath the base there is insulation to help hold the heat in and to protect anything beneath it from the high temperature of the collector. The outside walls (those facing the ambient air) of the collector should also be insulated. For a look at the basic thermal collector, see Figure 2.

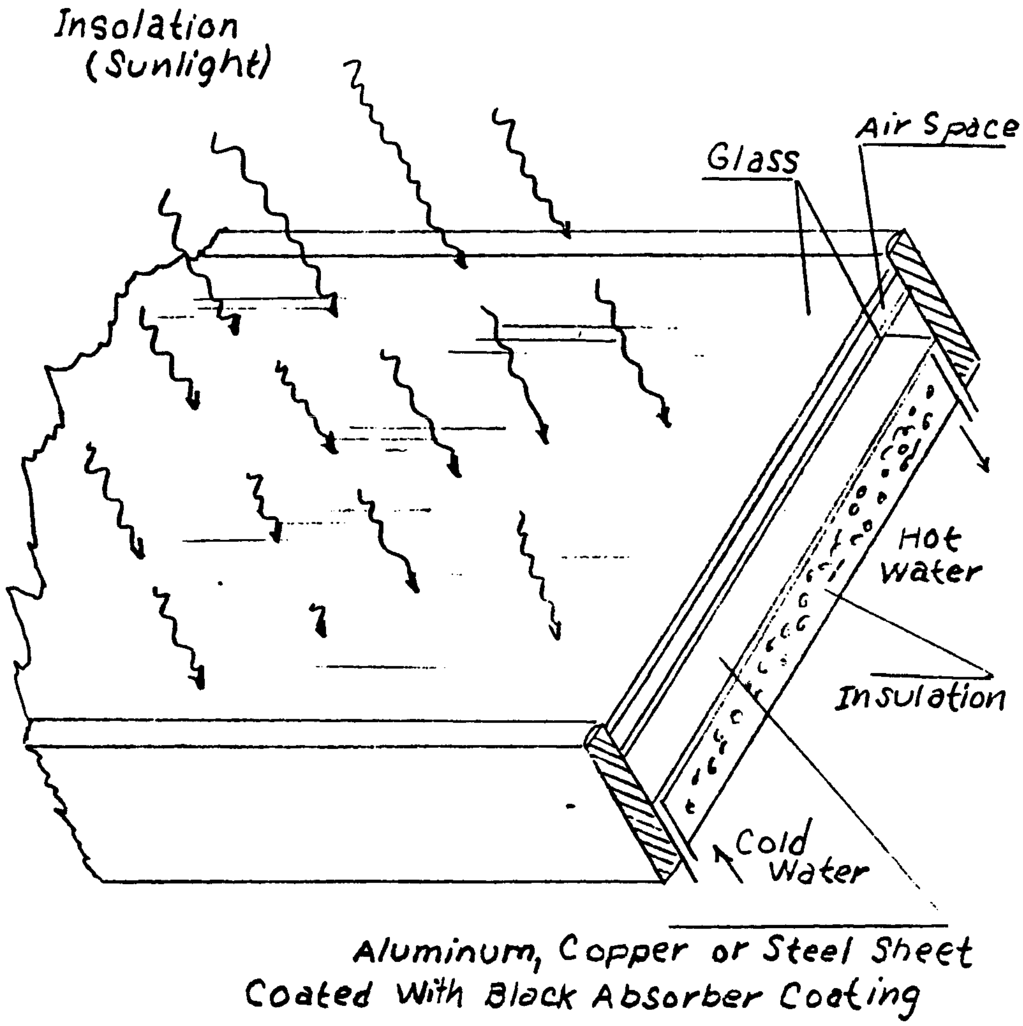
Thermal Storage Area

The storage area is necessary to the total system because we do not have a continuous supply of sunshine, and therefore there has to be some type of storage for the energy collected when the sun is shining. This energy is then used at times when the sun is not shining or when the weather is not allowing enough of the sun's rays through to enable the collector to work effectively.

The storage area for heat (energy) takes on many different forms. The type of storage depends mainly on the type of heat transfer medium that is used in the collector. If air is the transfer medium, rocks and bins of salts, or wax is used for storage. When water is the medium, then it can be stored in large tanks and/or in combination with rocks.

The salt most commonly used is called Glauber's Salt (sodium sulfate decahydrate). This salt melts at a temperature of 90°F. When melting, it takes in a large amount of heat which it releases when it recrystallizes.[3] When using

[3] Maria Telkes, "Energy Storage Media," in Proceedings of the Solar Heating and Cooling for Buildings Workshop, ed. Redfield Allen (Washington, D.C.: Government Printing Office, 1973), p. 57.



FLAT-PLATE SOLAR COLLECTOR

FIGURE- 2

Glauber salt, it must be placed in "heat bins" with the hot air circulating around the bins for the salts to absorb the heat.

The wax currently used for storing heat is ordinary paraffin wax. It is used in the same manner as the salts, in specially designed bins.

Besides the collector and the storage area, there is the associated equipment that makes the system function properly. This equipment consists of the necessary pipes or ducts for the transfer of the medium, thermostats, control box, valves, and a pump or fan, depending on the transfer medium.

All of these systems function in roughly the same manner. When the thermostat in the collector senses that (1) there is enough heat to warm the transfer medium, (2) the tank temperature is below 200°F., and (3) a ten degree difference exists between the collector and storage temperature, the pump or fan is turned on.[4] This circulates the water or air through the collector and back to the storage area where it will increase the amount of heat (energy) stored. When the thermostat senses that not enough energy is being absorbed by the collector or that the temperature in the storage tank has reached 200°F., the pump will cease operation.

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[4]Richard A. Tybout and George O. G. Löf, "Solar House Heating," Natural Resources Journal 10 (April 1970): 273.

Heat Transfer Mediums of the Collector

Before continuing, it is necessary to analyze hot air as a transfer medium versus hot water. The advantages of the hot air are its high durability, good efficiency at moderately high temperatures, nothing to freeze, no pressurizing required, and the lack of possible building damage if a leak should occur.

It also has disadvantages. There is difficulty in finding air leaks, and large heat ducts are necessary for transporting the air. These ducts cause the system to be more expensive than the hot water system.[5]

The flat-plate air collector (Figure 3) is similar to the water flat-plate collector, except that in the inside of the collector there are either baffles or plates, or a porous black material which is mounted to the base. This is for increased absorption area. These are then cooled by the passage of air at a low velocity (i.e., one foot per second) over and around the baffles or plates. Dr. Löf believes that the efficiency of the hot air system is higher than that of the hot water system.[6] However, this author agrees with Farrington Daniels that water is the best heat transfer

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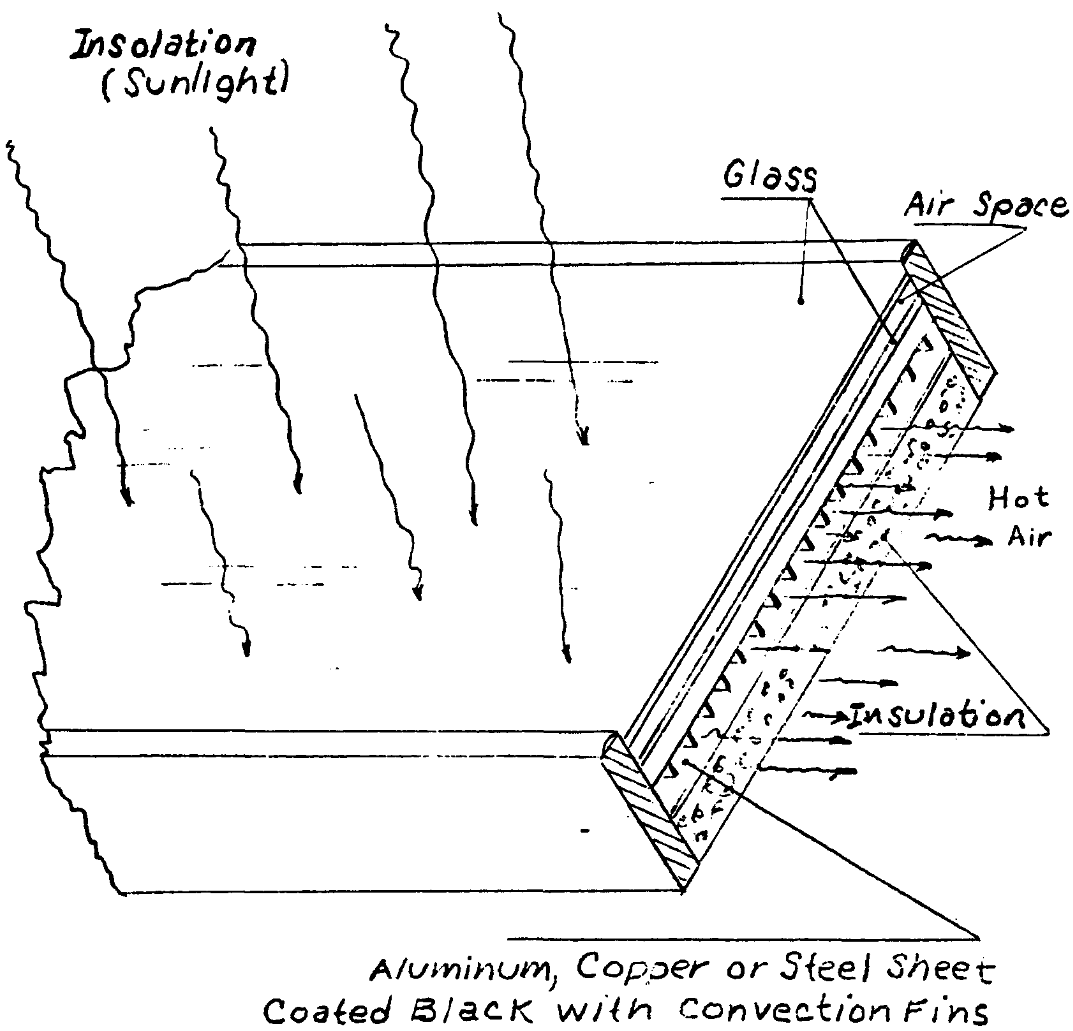
[5]George Löf, "Solar Air Heaters," in Proceedings of the Solar Heating and Cooling for Buildings Workshop, ed. Redfield Allen (Washington, D.C.: Government Printing Office, 1973), p. 52.

[6]Ibid.



HOT AIR

FLAT-PLATE SOLAR COLLECTOR

FIGURE-3

medium.[7] Even though the differences in efficiency of these collectors are small, when one includes the added costs for the heat ducts and the modified collectors of an air system, it is obvious that this is not the optimal system.

Water as a Transfer Medium

There are two methods of operating a water system. One method (an open system) uses gravity to feed the water from the top of the collector to the tank. The only pressurized portion is from the tank to the top of the collector. There is never any problem with freezing because most of the water drains to the tank.

The second method (a closed method) uses a pump to pressurize the entire system. In other words, not only is the water pumped to the collector, but through it as well. This is usually done through small pipes attached to the base of the collector. Since the system has to be pressurized, it creates the requirement for antifreeze because there is always water in the collector which could freeze and damage the collector. Another disadvantage of a pressurized system is that it requires a larger pump in order to create the pressure in the system and to move the required volume of water.

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[7]Farrington Daniels, Direct Use of the Sun's Energy, (New Haven, Conn.: Yale University Press, 1974; reprint ed., New York: Ballantine Books, 1975), p. 108.

While the pressure system does have one advantage in that the water can be heated to a higher temperature, this increase in thermal efficiency does not outweigh the enormous cost of the extra piping needed in the collector or the cost of a larger pump. Therefore, the open method will be used in this study because it is more economical and is as efficient (for all practical purposes) as the closed system.

Storage Area for Water

If one selects a water system, some forms of energy storage (salts and wax, in particular) are eliminated. Two forms remain: an insulated water tank, and a water tank and rocks combination. The advantage of rocks is that they are slow to absorb heat, they are also slow to release heat. This is especially important in areas where a long duration of cloud cover is probable.

The final determination of an optimum storage area will be done in Chapter III. For now, however, an insulated water tank will be considered in order to aid in the computations of the size needed for an average home.

Optimum System

In summary, the author believes that a solar energy system for the direct conversion of the sun's rays into a useable form of energy (heat), in the form of a thermal energy collector which uses the standard flat-plate collector with water as the heat transfer medium, is optimum.

This system should operate with the necessary thermostats and controls in order to maintain the optimal heating capability and also incorporate the open system of operation in order to keep costs at a minimum.

Having selected a solar heating system, it is important to determine the energy in BTUs for the heating of an average size home in Central Montana. Many real estate agents agree that the average size home sold in the Great Falls area is eleven hundred (1,100) square feet.[8] Since Great Falls is located in Central Montana, it is assumed to be a good representative of the area, and therefore much of the following data used in this study, including home size, energy received (Langley's), energy consumption, etc., was collected in Great Falls.

Once we know a house size in square feet, it is possible to determine the necessary heating requirements; however, this is not easily done. The usage actually varies substantially from home to home. Richard A. Grot, of Princeton, conducted a survey of ninety-eight three-bedroom townhouses in New Jersey having the same architectural design and found the average space heating consumption of 958 therms and a standard deviation of 141 therms (a therm being an equivalent in calorific power to 100,000 BTUs).[9] Therefore,

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[8]Interview with Mrs. T. Kinney, Mather and Associates Realty Company, Great Falls, Montana, 9 March 1976.

[9]Richard A. Grot, "Energy Utilization in a Residential Community," in Proceedings of the Solar Heating and Cooling

with such little correlation, at least in this sample, between energy consumption and family size and family income, the average heating load needed in BTUs per home will be used.

For a home of eleven hundred square feet, the space heating load will be approximately 16,500 BTUs per degree day.[10] A degree day is found by averaging the maximum temperature and the minimum temperature and either subtracting from sixty-five degrees to obtain the heating degree days or adding to sixty-five degrees to obtain the cooling degree days. This, coupled with the domestic hot water requirement of twenty gallons per person per day (assuming a family of four), amounts to 16,500 BTUs per day.[11] This added to the heating load equals the total heating load of an average size home (see Table 1).

Knowing the total heating load and the amount of energy received from the sun in Central Montana (see Table 2), one can calculate the size of the collector and storage area needed to meet most of the heating requirements of an average size home. It is not practical or economical to try to meet the total heating load of an average size home[12]

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for Buildings Workshop, ed. Redfield Allen (Washington, D.C.: Government Printing Office, 1973), p. 95.

[10]Tybout and Löf, "Solar House Heating," p. 269.

[11]G. O. G. Löf and R. A. Tybout, "The Design and Cost of Optimized Systems for Residential Heating and Cooling by Solar Energy," Solar Energy 16 (May 1974): p. 11.

[12]Ibid., p. 18.

TABLE 1

MONTHLY HEATING REQUIREMENTS (IN BTU'S)

Month	(1) Degree Days[a]	(2) Avg. Monthly Heat Loss[b]	(3) Domestic Hot Water[c]	(4) Thermal Load (2 + 3)	(5) Solar Contribution (from Table 2)	(6) % of Total Requirement	(7) Auxiliary Required (2 - 5)
Jan	1380	22,770,000	511,500	23,281,500	4,789,500	.21	18,492,000
Feb	1075	17,737,500	462,000	18,199,500	7,140,000	.39	11,059,500
Mar	1070	17,655,000	511,500	18,166,500	11,997,000	.66	6,169,500
Apr	648	10,692,000	495,000	11,187,000	12,712,500	1.00	---
May	367	6,055,500	511,500	6,567,000	14,461,500	1.00	---
Jun	162	2,673,000	495,000	3,168,000	14,602,500	1.00	---
Jul	18	297,000	511,500	808,500	17,484,000	1.00	---
Aug	42	693,000	511,500	1,204,500	16,112,250	1.00	---
Sep	260	4,290,000	495,000	4,785,000	12,915,000	1.00	---
Oct	524	8,646,000	511,500	9,157,500	8,997,750	.98	159,750
Nov	912	15,048,000	495,000	15,543,000	5,085,000	.33	10,548,000
Dec	1194	19,701,000	511,500	20,212,500	3,813,000	.19	16,399,500
Totals (Year)	7652	126,258,000	6,022,500	132,280,500	130,110,000		62,738,250

[a]SOURCE: U.S., Department of Commerce, National Oceanic and Atmospheric Administration, Climatography of the United States No. 84, (Asheville, N.C.: National Climatic Center, 1973), pp. 317-18.

[b]16,500 BTUs per Degree Day (heat load for 1100 square feet home) multiplied by Degree Days per month.

[c]16,500 BTUs per day (domestic hot water load for a family of four) multiplied by days in the month.

through solar energy; therefore, supplemental heating will be required.

From Table 1 it can be seen that, with an average total heat load of 132,280,550 BTUs, a collector of 750 square feet is needed to meet a requirement of 60 to 70 percent of the heating load eight out of the twelve months of the year. The necessary storage area is directly related to the collector area by 15.4 pounds of water per each square foot of collector area.[13]

For 750 square feet of collector, there is a need for:

750 x 15.4 pounds = 11,550 pounds
1 gallon - 8.338 pounds = 1385.2 gallons

For optimum storage area, one will assume 1,500 or 2,000 gallons of water (1,000 gallons of water can store approximately 320,000 BTUs). In order to ease computations of the costs, the optimal size of the storage area will be determined in Chapter III.

Heat Exchange System

Finally, in order for a home to benefit from the solar energy system, an interface or heat exchange is needed between the solar energy system and the house heating system. It applies both to an existing home and to new home construction. As was previously mentioned in this chapter, it is not feasible to use solar energy to meet the total heating load

[13] Ibid., p. 17.

TABLE 2

SOLAR COLLECTION

Month	Solar[a] Insulation (in Langley's)	Tilt[d] Angle Percent	62°[c] Plane	3.687 BTUs/ Langley	.40[b] Overall Efficiency	Average[e] Daily Collection	Average[f] Monthly Collection (in BTUs)
Jan	140	.9976	139.6	515	206	154,500	4,789,500
Feb	232	.9945	230.7	851	340	255,000	7,140,000
Mar	366	.9563	350.0	1290	516	387,000	11,997,000
Apr	434	.8830	383.2	1413	565	423,750	12,712,500
May	528	.7987	421.7	1555	622	466,500	14,461,500
Jun	583	.7548	440.0	1622	649	486,750	14,602,500
Jul	639	.7987	510.3	1881	752	564,000	17,484,000
Aug	532	.8830	469.7	1732	693	519,750	16,112,250
Sep	407	.9563	389.2	1435	574	430,500	12,915,000
Oct	264	.9945	262.5	968	387	240,250	8,997,750
Nov	154	.9976	153.6	566	226	169,500	5,085,000
Dec	112	.9946	111.3	410	164	123,000	3,813,000
Total (Yearly)							130,110,000

[a]SOURCE: U.S. Department of Commerce Environmental Science Services Administration, Climatic Atlas of the United States (Washington, D.C.: Government Printing Office, 1968), p. 70.

[b]J. Richard Williams, Solar Energy Technology and Application (Ann Arbor: Ann Arbor Science Publishers, Inc., 1974), p. 9.

[c]Fifteen degrees was added to 47° (latitude of Great Falls) in order to get the maximum energy out of the sun's rays.

[d]See Appendix.

[e]Efficiency (BTUs per square foot) is multiplied by 750 square feet (size of collector).

[f]Daily collection (BTUs) multiplied by days in the month.

requirements of a home. Therefore, there must be some type of auxiliary heating system present in order to heat the home after a long duration of cloudiness and to aid in extremely cold weather.

This supplemental heating system may be tied into the solar heating system or be separate as is the case with electric radiant heat. This author feels that a supplemental system should be tied into the solar energy system for economies of scale.

The two most common heating systems presently used in Great Falls are forced hot air (gravity-fed in some older homes) and hot water heat. Thus, one needs to examine the heat exchange system for these two systems.

The heat exchange system for a forced hot air system depends mainly on the type of storage area that is used. If a water tank is used, then a heat exchanger similar to a car radiator is used. The hot water from the storage tank is circulated through the exchanger and the air blown through the exchanger is then distributed throughout the home. When the storage area consists of a tank surrounded by rocks, all that one has to do is to place small ducts in the rocks. Then, by blowing air through the ducts which absorb heat from the rocks, the heat is passed on to the air. This air is, in turn, then distributed through the home. A lot of people, including Mr. Thomason of Washington, D.C., do not use ducts among the rocks, but try to leave enough air space so that air can be circulated around them (see Figure 4 for the schematic of Mr. Thomason's house).

A house's hot water heating system and its heat exchanger are quite different from the forced hot air system. Theoretically, one could pump the hot water from the collector straight through the storage area and into the home; however, this is rarely done. In fact, most of the time they are two completely separate systems using separate water supplies, with the one (house heating) circulating through the storage area absorbing the heat as it passes through (see Figure 5).

The main disadvantage of the hot water system is that the water must be heated to between 140°F. and 160°F. in order to convert enough heat to warm a home. A forced hot air system need only have an air temperature of around 80°F. in order to warm a home.[14] This means that with a hot air system the collector can run more efficiently and the storage area will last longer (temperature-wise) to provide longer periods of solar heating. The optimal heat exchanger for a forced hot air system will be determined in Chapter III. The hot water system has been eliminated because of the excessive temperatures (140°F. to 160°F.) needed for a hot water system to efficiently heat a home. This also would put a terrible strain on the solar energy system and severely cut its efficiency.

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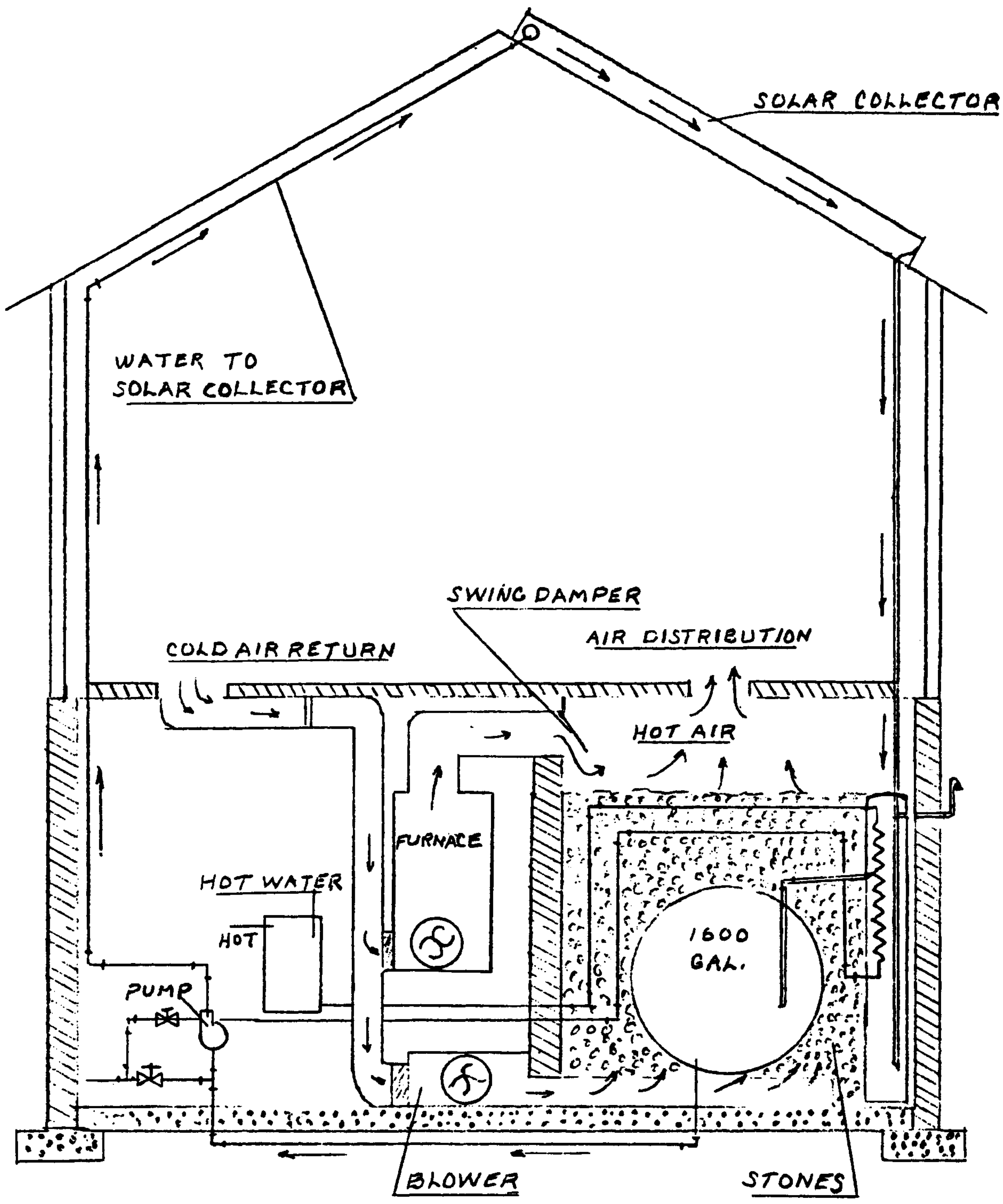
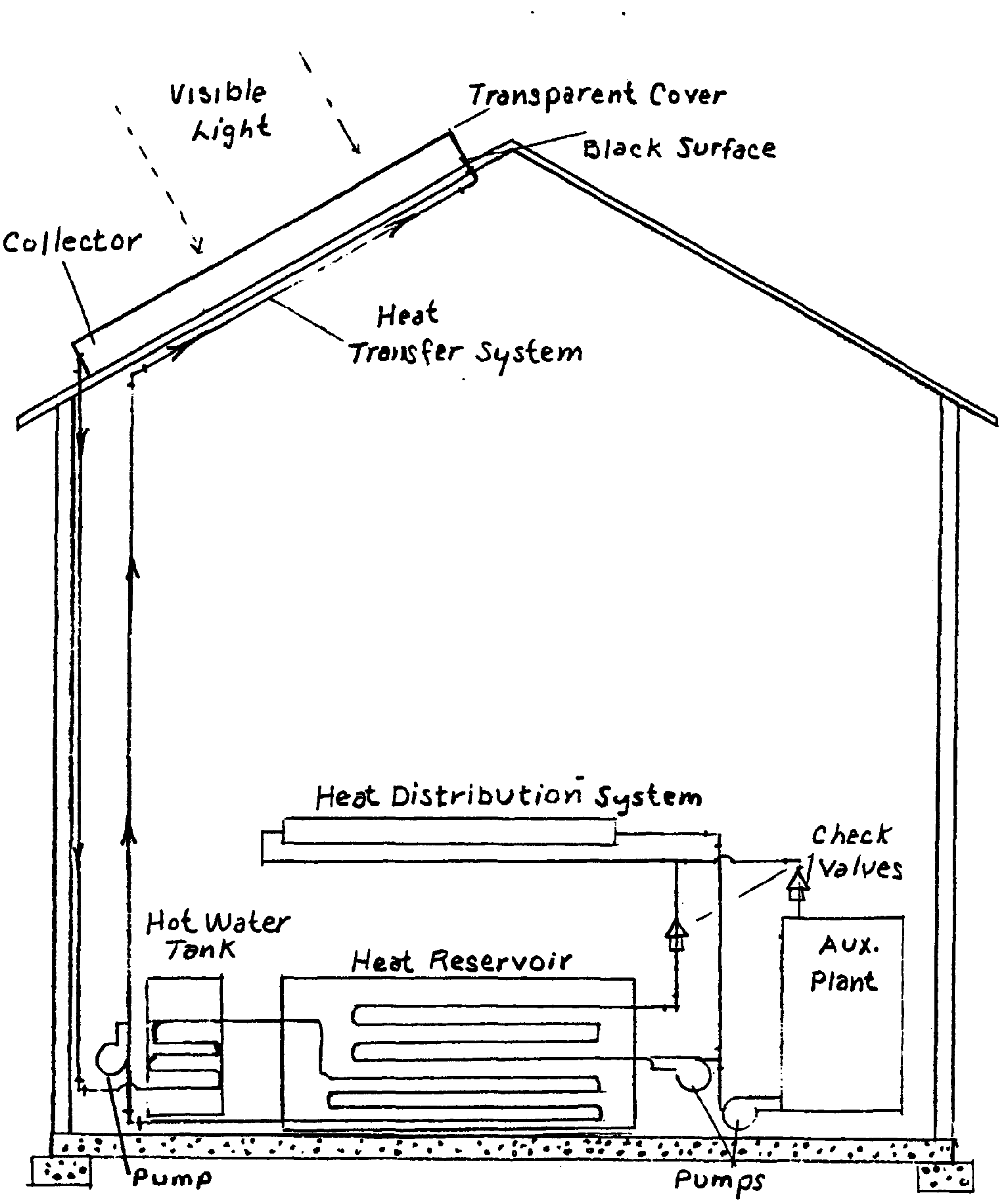
[14]Allen L. Hammond, "Individual Self-Sufficiency in Energy," Science 184 (April 1974): 279.



THOMASON-TYPE SOLAR HEATING SYSTEM

FIGURE-4



SOLAR HEATING SYSTEM FOR HOT WATER HEATING

FIGURE- 5

CHAPTER III

FINANCIAL ANALYSIS

Solar Energy System Cost Factors

Collector Cost Factors

In order to construct a solar collector, materials and techniques must be available in the area. Central Montana cities, because of their size and distance from major metropolitan distribution areas, are at a disadvantage with respect to acquiring such materials. They must rely in part on other parts of the country for materials and techniques.

One of the most economical collectors currently found on the market is the "open flat-plate" collector which Edmund Scientific Company of New Jersey sells for $4.00 a square foot (excluding shipping or installation charges).[1] An alternative to buying such a ready made unit is to price the necessary materials for a collector and determine the cost of having it constructed.

The materials needed for a collector include glass, wood, sheet steel, and paint. The most economical glass to use in a collector is the standard patio door, mass produced

[1]Richard F. Dempewolf, "Sunpower: The heat's on for real," Popular Mechanics, September 1975, p. 64.

in a 34-by-76-inch size. For 750 square feet, one would require forty-two such units at a cost of $2.50 per square foot (see Table 4 Appendix). Any other type of glass arrangement specially built would cost roughly $5.00 per square foot of glass coverage.[2]

Using standard glass patio doors, a frame or cradle must be constructed to hold them in place on the roof. Redwood is used for the frame because of its excellent resistance to moisture and heat from the collector. For a collection of forty-two units, one would require approximately $91 in wood (see Table 4 Appendix) in order to encase each sheet of glass in its individual cradle (support).

The next portion of the collector is the flat-plate or metal base over which the water flows. The most economical material to use is steel (see Table 4 Appendix) at a cost of $10 per sheet or a total cost of $210 to cover 750 square feet.

The final collector cost is the paint or coating used on the steel to enhance the absorption qualities. Even though acrylic flat black paint costs more than regular flat black paint ($19 versus $8.85 per gallon), this author feels that maintenance costs over the long run are less with this paint than with other types.

It is important here to determine the overall cost per square foot of the collector in order to have some basis for

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[2]Interview with Jay Fabrega, House of Glass, Great Falls, Montana, 2 April 1976.

future calculations. With material costs of $2,223 added to labor costs of $1,598, the total cost is $3,821 (see Table 5 Appendix). This amount averages to a cost per square foot of the collector of $5.09.

Storage Cost Factors

The second biggest investment is in the storage area. Since water will be used as the heat transfer medium, the only possible means of storage is a large holding tank, or a holding tank surrounded by rocks, to enhance the heat retaining characteristics. Given 15.4 pounds of water per square foot of the collector from Chapter 2 (which, under average conditions, relates from one to two days of heating capability) at a minimum, a tank with a capacity of 1,385 gallons is needed. However, the storage area could be 1,500 to 2,000 gallons, depending on the cost. It was found that for Great Falls most tanks came in 1,000 gallon increments; therefore, the cost of a 2,000 gallon tank was used for cost purposes. The most economical tank was a 2,000 gallon steel tank costing $540 (see Table 4 Appendix). Added to this is a $50.00 cost for insulating the tank.

Connected with the storage area is the heat transfer system that will be used to heat the air distributed throughout the home. In Chapter 2, such a transfer system was narrowed down to either a "radiator" type heat exchanger or the natural convection of heat from the tank to the rocks, which is later passed on to the air.

In determining the optimum storage area and the optimum exchange system, the costs of these two systems must be compared. The storage area consisting of the tank and rocks acts the same in principal as the water tank and heat exchanger. Therefore, the costs of using rocks versus the cost of using a heat exchanger will be compared.

In analyzing a heat exchange and storage area composed or rocks, one must include the cost of a retainer wall to hold the rocks and the extra cost of insulating these walls. Assuming the use of a corner in a basement, there would only be the need for two extra walls. The needed area for a storage tank of 9.9 cubic yards and the 25 cubic yards of rocks would be roughly an area 11 1/2 feet by 12 feet by 7 feet high. Two additional concrete walls 12 feet long would cost roughly $240.[3] Added to this would be the cost of insulation which would amount to $210 for all four walls.[4] Finally, the cost of the rocks at $1.25 per cubic yard must be considered. For 25 cubic yards, or roughly thirty tons, this would cost $32.[5]

The total cost of a heat exchange system using rock is $482, versus the $218 for a coil-type heat exchanger with

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[3]Interview with Larry Eliason, First Builders Company, Great Falls, Montana, 2 April 1976.

[4]Interview with Bob Erickson, Bob's Enterprises, Inc., Great Falls, Montana, 2 April 1976.

[5]Interview with Frank Bedosky, Sun Sand and Gravel, Sun River, Montana, 18 March 1976.

insulation for the tank (see Table 4, Appendix). From an economic standpoint, a coil heat exchanger is optimum (see Figure 6).

Plumbing and Control Cost Factors

A third cost factor is represented by the controls and the pumps used in the system. The control system for solar energy is very important, for without it one would not maintain the temperatures necessary for efficient operation. The control must be sensitive enough to respond to changes in the collector temperature and respond accordingly (as previously discussed in detail in Chapter 2), to either turn the pump on or off. A Honeywell system is the only system that can be purchased locally at a cost of $340. However, there are other controls available for roughly $150 (not including shipping). A 1/3 h.p. pump costs $200. The other pump for circulating water through the heat exchanger costs $134. Other accessories, including thirty feet of 3/4 CVPC plastic piping at a cost of $13.43 and forty-five feet of three-inch high temperature pipe at a cost of $112.50, are needed.

Wiring the controls and pumps is tedious, as are the necessary plumbing tasks. For this reason, the labor costs are high--approximately $1,000[6] (see Table 5, Appendix). Combining all costs for material and labor, a solar energy

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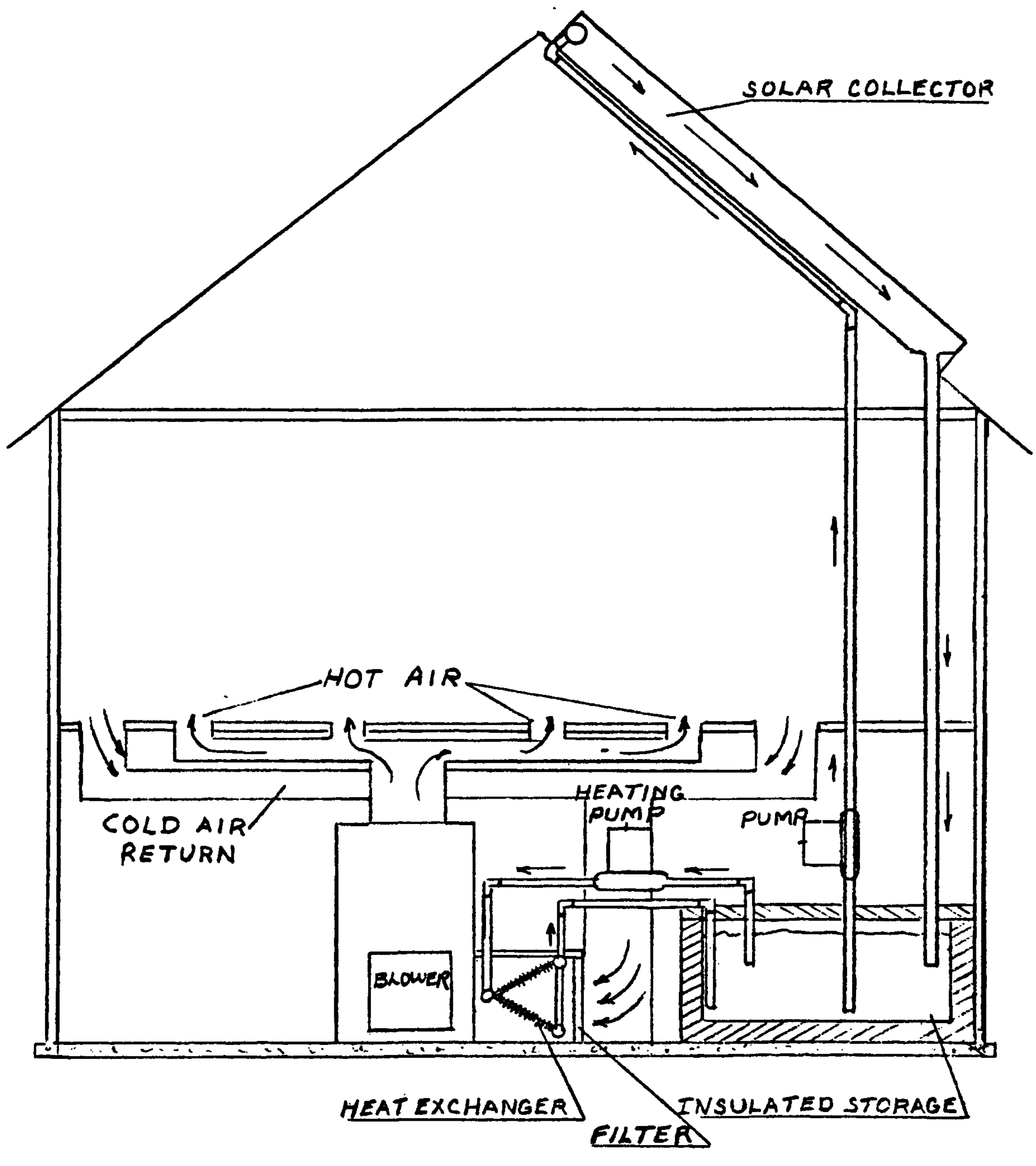
[6]Interview with Vern Waldenberg, Central Plumbing and Heating Company, Great Falls, Montana, 7 April 1976.



SOLAR HOT WATER TO HOT AIR HEATING SYSTEM

FIGURE - 6

system of the type outlined in this paper costs $6,189, which amounts to $8.25 per square foot of collector.

Commercial Power Cost Factors

In order to determine the feasibility of solar energy for the heating of homes, one must know the cost of heating a home with natural gas and electricity for comparison. The most common fuel for heating homes in Central Montana is natural gas. In 1975, the Great Falls Gas Company had an average of 19,573 residential meters in use. They also calculated in the same period that 509,304 mcf of gas was used for the heating of homes.[7] This figure was obtained by subtracting the gas usage for non-heating items like gas lights and grills, and house appliances like gas dryers and stoves. This averages out to 128.2 mcf per residence, at a cost of $197.93 annually. This is based on rates as of March 15, 1976 of:

$3.67 - - - - - - - - - - - -	10 ccf
$ .582 per ccf - - -	10 - 990 ccf
$ .1343 per ccf - - -	990 - 2000 ccf

Electricity is also used to heat homes, and is especially prevalent in outlying areas where natural gas is not available. The average size home (1,000 square feet) in the

[7]Interview with Bill Quast, Great Falls Gas Company, Great Falls, Montana, 19 March 1976.

state uses 21,000 kwh for heating during a typical year.[8] This amounts to $325.50 per year, based on rates as of March 1976 of:

$1.40 - - - - - - - - - - - -	20 kwh
$ .0444 per kwh - - - -	20 - 100 kwh
$ .0311 per kwh - - - -	100 - 200 kwh
$ .0155 per kwh - - - -	200 kwh and up

For usage of 21,000 kwh, Montana Power Company would charge an average rate of $.0155 per kwh.

It has been mentioned several times that a solar energy system will not supply the total heating load of a home. Therefore, the associated cost of a supplemental heating system must be taken into account when determining the feasibility of a solar energy system. This is especially true in the case where the homeowner wants electric heat for his auxiliary heating source. He must include the cost of extra ducts for transporting the hot air from the storage area. Therefore, a person wanting to use electric heat as the auxiliary must then include an additional $470 to $500 for this extra duct work.[9]

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[8]Interview with Leonard Regan, Montana Power Company, Great Falls, Montana, 25 March 1976.

[9]Interview with Gary Winchell, Falls Sheet Metal Works, Great Falls, Montana, 23 March 1976.

Cost Comparison

A method must be employed to reduce the value of future fuel dollars to present value by discounting the costs of fuel savings in the future to the present. It is important to be able to discount fuel costs to present when fuel costs continue to rise. To calculate the present value of a yearly cost (Yo) escalating at a fixed rate each year for L years:[10]

$$P = Yo \sum_{t=1}^{L} \left(\frac{1 + g}{1 + r}\right)^{t}$$

where r is the discount rate, Yo is the current yearly cost of fuel, L is the number of years the solar energy system is expected to operate, g is the anticipated growth rate of fuel costs each year, t is a given year and P is the present value of fuel costs for L years.

A discount rate of 8 percent was used in this analysis, which approximates current mortgage rates. This rate is fairly high by historical standards and reflects the high rates of inflation of the past. It is assumed that inflation will continue and, hence, mortgage rates will remain high. An investor could also currently expect to realize an 8 percent

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[10] U.S., Department of Commerce, National Bureau of Standards, Solar Heating and Cooling in Buildings: Methods of Economic Evaluation, by Rosalie T. Ruegg (Washington, D.C.: Government Printing Office, May 1975), p. 9.

return on his money with a minimum of associated risk (tax free municipal bonds).

The time frame used for the present value analysis was twenty years. This author feels that the solar energy system can last this long with only minor maintenance (i.e., painting, glass replacement, and wood replacement). Glass replacement would not be any more common than the normal breakage of windows in a house. All of the maintenance costs incurred would not be any more common than the normal maintenance requirement on a home.

The growth rate (cost) for fuels from 1975 to the year 2000 vary quite a bit. In fact, Hudson and Jorgenson determined that natural gas will increase in price at a yearly rate of 6.5 percent, whereas electricity will only increase 3.5 percent per year.[11] These rates have been used in determining the present value of fuel costs.

Natural Gas

First, the present value of twenty years of natural gas heating was determined. Using the equation presented earlier, one has:

$$P = \$198 \sum_{t=1}^{20} \left(\frac{1 + .065}{1 + .08}\right)^t$$

[11] Edward A. Hudson and Dale W. Jorgenson, "U.S. Energy Policy and Economic Growth, 1975-2000," *The Bell Journal of Economics and Management Science* 5 (Autumn 1974): 493-94.

This results in a present value for natural gas over twenty years of $3,429.87 (see Table 3).

Electricity

Substituting the known factors into the basic equation, one determines the following for electricity:

$$P = 326 \sum_{t=1}^{20} \left(\frac{1 + .035}{1 + .08}\right)^t$$

This results in a present value for electricity over twenty years of $4,295.98 (see Table 3).

Summary of Comparison

Comparing the initial cost of a solar energy system, $6,189, to the present value of natural gas and electricity costs over twenty years, one finds that for this particular study it is not economically feasible to use solar energy for the heating of homes, even if the present system (750 square feet of collector, 2,000 gallon storage tank, etc.) supplied the total heating requirements of an average size house. If the auxiliary fuel for heating the home is added to the initial cost of the solar energy system, the economic difference becomes even greater, and the feasibility of such a system is very questionable. However, this author feels that solar energy can still be used in certain circumstances in Central Montana (see Chapter 4).

TABLE 3

PRESENT VALUE

Year	Gas	Cumulative Totals	Electric	Cumulative Totals
1976	$ 195.25		$ 312.41	
1977	192.53	$ 387.78	299.40	$ 611.81
1978	189.86	577.64	286.91	898.72
1979	187.21	764.85	274.95	1,173.67
1980	184.62	949.47	263.47	1,437.14
1981	182.04	1,131.51	252.49	1,689.63
1982	179.03	1,311.04	241.96	1,931.59
1983	177.03	1,488.07	231.88	2,163.47
1984	174.56	1,662.63	222.20	2,385.61
1985	172.14	1,834.71	212.94	2,598.61
1986	169.75	2,004.52	204.08	2,802.69
1987	167.39	2,171.91	195.57	2,998.26
1988	165.05	2,336.96	187.39	3,185.65
1989	162.76	2,499.72	179.59	3,365.24
1990	160.50	2,660.22	172.10	3,537.34
1991	158.26	2,818.48	164.92	3,702.26
1992	156.06	2,974.54	158.05	3,860.31
1993	153.91	3,128.45	151.46	4,011.77
1994	151.71	3,280.22	145.14	4,156.91
1995	149.65	3,429.87	139.07	4,295.98
Total	$3,429.87		$4,295.98	

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Even though solar energy is not presently economically feasible as a heating source for the average size home in Central Montana, this does not mean that solar energy cannot be used in the future. Technological changes and price reductions in the solar energy components due to mass-production will help foster the use of solar energy systems over time.[1]

The reason for a further price decline in the cost of solar energy components is that there are numerous companies producing solar components, but none mass-producing them. In order for a company to obtain economies of scale in production, enough units must be produced to write off research and development costs and to contribute toward overhead expenses. Such cost reductions will have a great impact on the use of solar energy systems in the future, especially in the marginal areas of the country like Central Montana where presently the large capital outlay of the large collectors and associated equipment prohibit their use.[2]

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[1]Hammond, "Self-Sufficiency in Energy," p. 278.

[2]Wilson Clark, <u>Energy for Survival: The Alternative</u>

The point should be made that, even though solar energy systems are not presently feasible in Central Montana, other parts of the country including New England, Arizona, California, Florida, etc., are successfully using solar energy for the heating of homes.[3] In some parts of the country, where electricity rates are very high, solar energy is the only alternative that is economically feasible because these areas of the country are not served by natural gas or heating oil.[4]

Presently, however, if one could get more consistent use out of the same system by placing it in a multi-unit dwelling--a school or a commercial building--a solar heating system may be feasible for use in Central Montana. These units may be feasible because of their low heat loss (fewer outside walls), high hot water and heating loads (as a percent of total load), and economies of scale (one storage tank versus many tanks and pumps for the same number of families in a single residence).[5]

A very important area when dealing with the heating of homes is the area of insulation, regardless of the source of energy. Without the proper insulation, any heat gain

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to Extinction (New York: Doubleday, 1974), p. 469.

[3]Tybout and Löf, "Solar House Heating," p. 277.

[4]Faltermayer, "Solar Energy is Here," p. 106.

[5]Solar Heating and Cooling of Buildings, 3 vols. (Redondo Beach, California: TRW Systems Group, 1974), vol. 1: Executive Summary, p. 3-11.

from solar energy or other sources will be needlessly wasted. In recent years, people have recognized the need for the proper insulation of their homes. In turn, the builders have been motivated to put more in the homes instead of worrying about the initial cost involved, as they did previously.

One of the problems of solar heating stems from the very large capital expenditure needed for the initial equipment. However, if one could build a smaller system (e.g., solar water heater), the capital outlay would be smaller and the payback would be sooner, thereby becoming economically more attractive. Solar water heaters, besides being in existence since the 1930s (see Chapter I), are substantially more economical than solar heating systems for all buildings and all regions. This is mainly due to the lower costs of the system, as well as the stability of the hot water load over the year[6] (see Table 1 in Chapter II). A schematic of a residential system can be seen in Figure 7. It functions the same way as the hot water heating system described at the end of Chapter II.

The initial capital outlay for this system is smaller than for a total heating system (usually $1,000 to $1,600 versus $5,000 to $7,000); thus, it may be more likely to be feasible than a total heating system, depending on the initial cost and the fuel costs for the area.[7]

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[6]Ibid.

[7]Faltermayer, "Solar Energy is Here," p. 106.

The United States uses over 4 percent of its total energy consumption to heat water.[8] The possible savings in fuel consumption, if everyone had a solar water heater, are tremendous. There are quite a few in existence already. In fact, the latest estimates say that there are over a million solar water heaters installed in the world.[9] In the United States, most of them are located in California and Florida (see Chapter I).

This conclusion must further be explained in order to put it in the right perspective. At the time of the writing of this paper, the United States imported--for the first time in its history--more oil than was produced domestically. Even though the United States used less energy in the last two years than the peak usage of 1973, the country is still very dependent on outside sources for its energy.[10] To gain energy independence the United States must use alternative sources of energy, as mentioned in Chapter I.

Especially pertinent are solar energy, wind energy, and geothermal energy because they are non-polluting in both thermal and ecological areas. However, people in the United States have not pushed for solar energy or other alternative forms of energy because it is cheaper to use fossil fuels.

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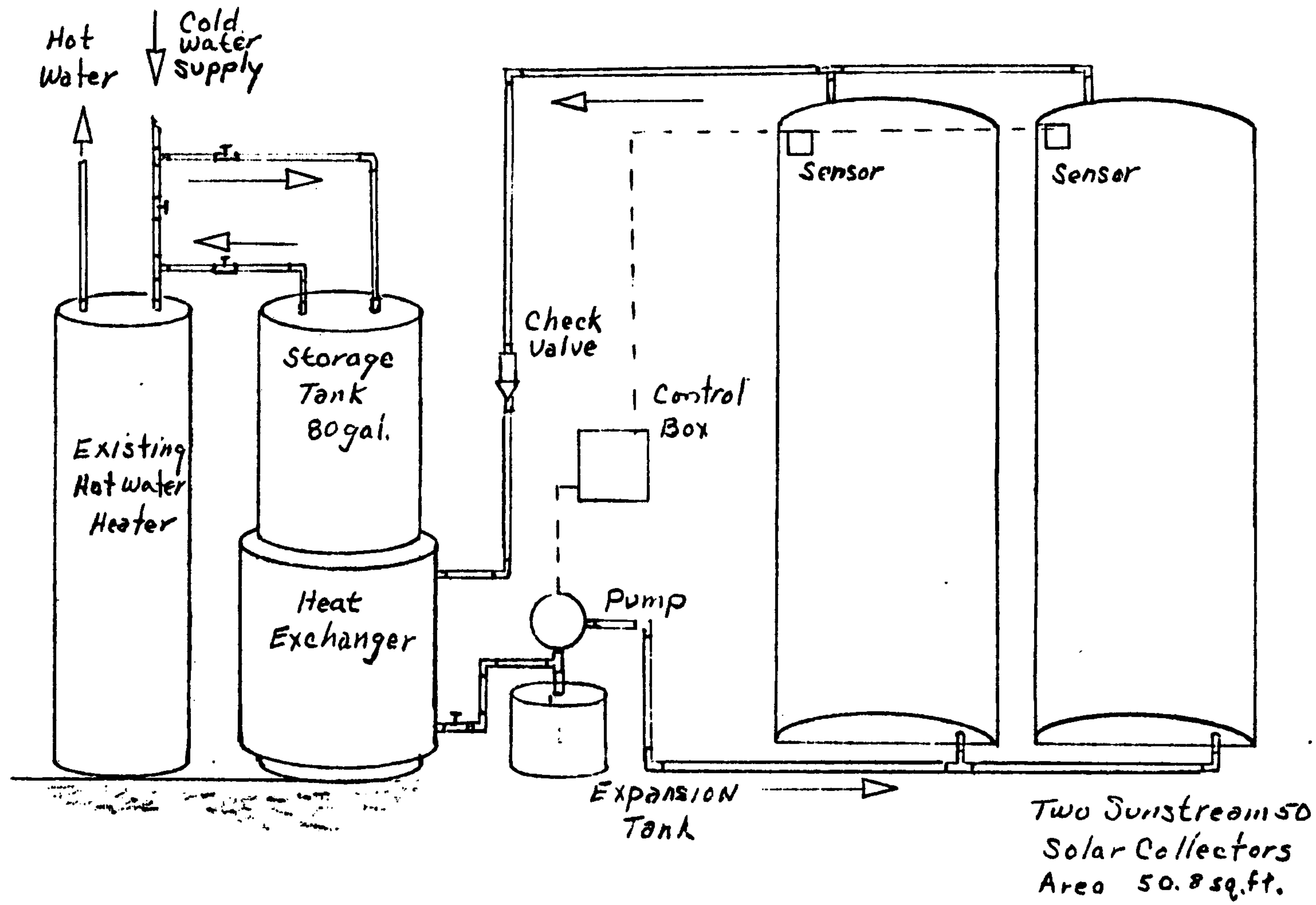
[8] Fisher, Energy Crisis in Perspective, p. 5.

[9] John L. Wilhelm, "Solar Energy, The Ultimate Power House," National Geographic 149 (March 1976): 385.

[10] "Nation's Energy Use Drops Again in 1974," Great Falls Tribune, 18 April 1976, p. 1.



SOLAR WATER HEATER

FIGURE - 7

As fossil fuels go up in price, maybe even doubling by 1985, we may finally realize the need for alternative sources of energy.[11] When this rise in prices takes place, the solar energy for heating of homes will become feasible for use, if not necessary.

Recommendations

While this paper covers the feasibility of solar energy for residential use, it is not an exhaustive study of all solar heating materials or techniques; nor does it meet the needs of all parties concerned with solar heating. The following areas would appear to require further effort:

1. A systematic investigation into the expected costs of operating, maintaining, and repairing solar energy systems (particularly flat-plate collectors), and the projection of future costs of solar energy components based on mass production.
2. A comprehensive analysis of the impact of laws, regulations, zoning ordinances, and government incentives on the costs of solar energy systems.
3. A more detailed analysis on the effect of increased fossil fuel prices on the use of solar energy systems by residential users.

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[11] Löf and Tybout, "Residential Heating and Cooling by Solar Energy," p. 18.

4. A comprehensive analysis on the attitudes of people toward solar energy and their different systems (e.g., water heaters and heating systems) and what the government and businesses can do to foster interest in the area of solar energy.

5. An analysis of the attitudes of people to the possibility of natural gas cut-offs, "energy moratoriums," or curtailment of the usual amount of gas available, and its effect on the use of solar energy systems.

APPENDIX

TABLES

TABLE 4

MATERIAL COSTS

Glass Door
(42 Units - 34"x76")

House of Glass: 42 @ $44.86 =	$1,884
Michotte Distributing Corp.: 42 @ $50.96 =	2,140

Wood (Redwood - 42 Units)

Madison & Johnson: 42-2"x4"x10' @ $3.31 =	$ 139
Poulson's: @ $2.90 =	122
Walker Lumber: @ $2.17 =	91

Metal (21 Units - 26"x20')

Pacific Hide & Fur:	
Steel @ $12.00 =	$ 210
Alum. @ $15.00 =	315
Weissman's:	
Steel @ $12.00 =	$ 252
Alum. @ $12.60	265

Plastic Pipe 3/4" CPVC

Montana Plbg. Supply: @ .4475 =@ .4475	$13.43
Poulson's: @ .45	13.50
Weissman's:@ .56	16.80

Tanks

Pacific Hide & Fur:	
Steel 1000 gal. =	$ 310
Steel 2000 gal. =	540
Steel 3000 gal. =	800
Weissman's:	
Steel 2000 gal. =	1000
B&K Tank Builders':	
Concrete 1000 gal. =	295

Paint
(Flat Black, Heat Resistant)

Columbia Paint Co.:	
Acrylic/gal.	$19.00
Oil/gal.	11.99
Sherwin-Williams Co.	
Oil/gal.	8.85

Sheathing
(1/2"x4'x8' - 25 Units)

Madison & Johnson: @ $2.25	$56.25
Poulson's: @ $2.19	54.75
Walker's: @ $2.50	62.50

Controls

Environmental Equipment Engineering Co., Inc.	$150
Honeywell (Industrial Control Set)	340

Pumps (1/3 H.P. High-Temp.)

Central Plumbing	$200
Hodges Plumbing	200

Pumps (Recirculating)

Central Plumbing	$165
Montana Pump	$134
Weissman's	135

Heat Exchanger

Trane Co.	$168

Insulation (ThermoCon)

Bob's Enterprises, Inc.:	
Tank - 2"	$ 50
Concrete Walls	210

Plastic Pipe (3")

Weissman's High-Temp. @ $2.50/ft.

TABLE 5

LABOR COSTS

Item	Cost
Cradle Construction (42 hours)	\$ 430[a]
Roof Installation beyond Normal (72 hours)	738[a]
Installation of Glass and Sealing	430[a]
Installation of Plumbing and Controls	875[b]
Installation of Tank and Heat Exchange	125[b]
Total	\$2,598

[a]Interview with Russell Jones, First Builders Co., Great Falls, Montana, 23 March 1976.

[b]Interview with Vern Waldenberg, Central Plumbing and Heating Co., Great Falls, Montana, 7 April 1976.

TABLE 6

SOLAR AZIMUTH AND ALTITUDE ANGLES

SUNTIME AM	SUNTIME PM	DEC 22 Azi.	DEC 22 Alt.	JAN 21 / NOV 21 Azi.	JAN 21 / NOV 21 Alt.	FEB 20 / OCT 23 Azi.	FEB 20 / OCT 23 Alt.	MAR 21 / SEP 21 Azi.	MAR 21 / SEP 21 Alt.	APR 20 / AUG 24 Azi.	APR 20 / AUG 24 Alt.	MAY 21 / JUL 23 Azi.	MAY 21 / JUL 23 Alt.	JUN 21 Azi.	JUN 21 Alt.
6	6							90	0	82	8	75	16	77	15
7	5							101	8	92	18	87	26	83	26
8	4	127	9	125	8	119	13	111	20	103	30	96	35	92	37
9	3	139	8	137	13	132	22	124	29	117	39	109	46	105	47
10	2	152	13	150	17	146	27	140	38	133	47	125	55	121	56
11	1	165	18	164	22	163	32	160	44	154	54	148	63	146	64
NOON		180	22	180	24	180	34	180	45	180	56	180	65	180	69

ZONE 4 – LATITUDE 42° 30′ TO 47° 30′

SOURCE: Clifford Stock and Richard L. Koral, Handbook of Air Conditioning, Heating and Ventilation (New York: Industrial Press, 1965), p. 1-72.

TABLE 7

TILT ANGLE PERCENTAGE

Tilt Angle Percent (cos i) is given by:

$$\text{Cos}(i) = \cos(b)\sin(a) + \sin(b)\cos(a)\cos(z)^{*}$$

where, a = the solar altitude at noon (see Table 6)
b = the tilt angle of the collector (62°)
z = the solar azimuth at noon (see Table 6)

Month	(a)	Cos(62)	Sin(a)	+	Sin(62)	Cos(a)	Cos(180)	
Jan	(24)	.4695	.4067	+	.8830	.9136	1	= .9976
Feb	(34)	.4695	.5592	+	.8830	.8290	1	= .9945
Mar	(45)	.4695	.7071	+	.8830	.7071	1	= .9563
Apr	(56)	.4695	.8290	+	.8830	.5592	1	= .8830
May	(65)	.4695	.9063	+	.8830	.4226	1	= .7987
Jun	(69)	.4695	.9336	+	.8830	.3584	1	= .7548
Jul	(65)	.4695	.9063	+	.8830	.4226	1	= .7987
Aug	(56)	.4695	.8290	+	.8830	.5592	1	= .8830
Sep	(45)	.4695	.7071	+	.8830	.7071	1	= .9563
Oct	(34)	.4695	.5592	+	.8830	.8290	1	= .9945
Nov	(24)	.4695	.4067	+	.8830	.9136	1	= .9976
Dec	(22)	.4695	.3746	+	.8830	.9279	1	= .9946

*SOURCE: M. N. Bahadori, "A Feasibility Study of Solar Heating in Iran," Solar Energy 15 (May 1975): 7.

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