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The Impact of Supplementary Active Air-Type Solar Heating Unit on a Conventional Heating System

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THE IMPACT OF SUPPLEMENTARY ACTIVE AIR-TYPE SOLAR HEATING UNIT ON A CONVENTIONAL HEATING SYSTEM

by

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This Thesis submitted by Roger D. Boe in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Date July 25, 1978

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ABSTRACT

The concern of this research was to investigate and determine impact of supplementary active air-type solar heating on a conventional heating system. A second concern involved a review of literature regarding the structural design of an active air-type solar heating unit.

This study attempted to: (a) determine the structural design of active air-type solar heatings by a review of literature, (b) collect data from a home utilizing air-type solar heating and conventional system, (c) analyze the data and determine the impact of air-type solar heating units on conventional heating systems, and (d) determine the combined effect of an air-type solar heating unit and conventional heating system in terms of economical implications.

Methods

The research design employed in conducting this study was the descriptive type. Data was compiled by the researcher from records at the University of North Dakota Geographical Weather Station and Northern States Power Company. Related literature was observed as to the design and function of air-type solar units. The least square test and energy calculations were used to interpret data. Data was arranged and presented in a graphic scatter diagram and narrative form.

Conclusions

The conclusions obtained from the analysis were: (a) supple-

mentary solar heating can upgrade efficiency of a home and enhance its design, (b) relationships between variables, seasons one and two as pre-treatment data, (c) post-test data demonstrated a significant difference from pre-test data, (d) this solar heating unit has no pay back consideration of installation cost, and (e) the data was not complete enough for a thorough analysis.

Recommendations

It is recommended that: (a) a study be done on varied thermostat settings, (b) an investigation be made into the development of solar economics by incorporating passive solar methods, and (c) a study be conducted in the area of solar energy and its applications for education.

CHAPTER I

INTRODUCTION

The United States presently faces two interrelated problems. The first problem pertains to the endangering of our environment by pollution from the by-products of our technological society. The second is concerned with the depletion of fuels which have enabled us to achieve a high standard of technological development. This perplexing dilemma has resulted in a nationwide investigation of alternative energy choices (1, p. 6).

Solar energy is a concept of growing interest and concern in today's society. The interest stems from the depletion of fossil fuels which has a consequence of higher prices. Everyone has felt this crunch in their homes, cars, etc. It is hoped that the use of solar energy will curb energy shortages and bring about reduced energy prices.

Mark Hyman (2, p. 29) held: Plenty of energy is beamed down to us from the sun . . . But the promise of gathering and using the energy in sunshine must be fulfilled in an economical way. In the past, economics has prevented widespread utilization of solar energy; at present, cost is still a major obstacle.

Statement of Problem

The problem under investigation in this study was to determine the impact of supplementary active air-type solar heat on the conventional heating system of a residential home.

The specific objectives were: (a) to review literature regarding the structural design active air-type solar heating units, (b) to collect data from a home utilizing air-type solar heating and conventional system, (c) to analyze the data and determine the impact of air-type solar heat units on conventional heating systems, and (d) to determine the combined effect of an air-type solar heating unit and conventional heating system in terms of economical implications.

General Hypothesis

There is no significant difference between the pre-test and post-test mean gas consumption resulting from air-type solar heating units as treatment.

Significance of the Problem

It has been established that there is a need for research in the field of solar energy (1,3,4,5,6,). This need is felt in every area of the world that consumes energy.

Braden (3, p. Forward) observed that the United States Bureau of Mines estimated the known global reserves of natural gas and petroleum to remain at the 1970 levels.

Everyone in the developing nations realizes that fossil fuels are limited in the world. This causes anxiety on the part of many individuals within these countries to keep prices for energy at a level that they can afford. The energy shortage has reached deep into the financial pockets of this nation and its people to pay rising energy costs.

As energy costs continue to increase and supplies are depleted, the need for new sources are increased.

Braden (3, p. Forward) indicated a rapidly diminishing reserve and the increased demand for energy are expected to drive fossil fuel prices up to an all time high. There will come a point in time when regardless of high prices, there will simply be no fossil fuels to be sold.

Lucas (4, p. 1) expanded the notion:

> What upsets a lot of people is that even while they are paying more for energy, they are using less, and that seems to defy economic sense . . . A congressional report says utility bills for Americans were up to $10 billion in 1974.

Professional people throughout the world are looking toward other sources of energy besides the conventional sources to provide an alternative supply of energy.

Truly people want to conserve national resources but not at the cost of denying themselves the normal standard of living they have enjoyed. Solar energy may offer much to fulfill this need. There are a number of possible options for consuming this alternative form of energy. People throughout this nation need to become aware of these possibilities.

There is tremendous potential of heating a house through passive and active solar heating techniques. If an individual incorporates either technique, he may be able to save on fuel bills in a home, trailer, cabin, etc. A source of unlimited supply of energy has been tapped and at no additional economical cost.

Limitations

This study was limited to a heating system that was predesigned and operated under normal weather conditions. A further limitation was that the experimental house involved modifications prior to the installation of the solar system. These modifications included additional insulation in the walls and a room addition.

Assumption

It has been assumed that the room temperature was kept between 68 and 72 degrees fahrenheit for pre-test and post-test data gathering. A further assumption was that the normal living activities in the house remained at a constant level.

Definition of Terms

The following is a list of terms that are used throughout the study.

Active air-type solar system - the use of external mechanical power to collect, store, and distribute the sun's heat to a building by means of air as a transfer fluid.

Conventional heating system - the form of heating that has typically been used to heat homes by using oil or gas as a source of energy.

Supplementary solar heating - a system of heating that obtains its energy from the sun to provide supplementary heat for a house.

Economical implications - financial savings in terms of less fuel consumption.

Efficiency - the amount of change in fuel consumption from pre-test to post-test data.

Degree day - a measure of the average annual temperature of a site; number of degrees below 65°F maintained as the average temperature of a specific site during one 24-hour period.

CHAPTER II

REVIEW OF LITERATURE

Solar energy is a concept receiving a large amount of publicity by news media. As a result, many believe that the concept of solar energy is a new idea. This is not correct. Solar energy and its application for mankind is simply the resurrection of old ideas. Loken, Somerville and Mathsen (5, p. 2) asserted: "This renewed thought has resulted from recent energy shortages prompting increased interest in developing alternative energy sources to replace or supplement dwindling resources."

Mankind has to choose an alternative energy source that is plentiful and economically feasible. Loken, Somerville and Mathsen (5, p. 2) explained that sunlight is one of the most abundant and uniformly available sources of energy known to man.

History of Solar Energy

Throughout the course of history many examples can be cited of solar energy meeting man's needs for energy. Intuitively, early man knew the advantages of building structures facing the sun so openings would capture warmth during the winter and exclude the sun's rays during the summer. Examples of such structures can be found in early Indian cultures (6, pp. 1,2).

Southwest Indian settlements located at Pueblo Bonito in Chaco Canyon, New Mexico is an example of such a culture. Built from 919 to

1180 A.D., the Pueblo once housed 1200 inhabitants within its semicircular structure. The determining points of the place's geometry were based on the position of the sun at the summer and winter solstices. At the University of Southern California, it has been revealed that Pueblo in its various stages of growth was so dimensioned that its surfaces were exposed to more solar radiation in winter than in summer. Wall and roof construction was varied in thickness and composition to store the sun's heat and to permit the proper time lag of day's heating effect into the interior at night. This all had the effect of a maintained temperature within the buildings interior as evenly as possible (6, pp. 1, 2).

A further example may be seen in the Acoma Pueblo near Albuquerque. A similar illustration of design in response to the daily and annual movement of the sun as was seen at Pueblo Bonito in Chaco Canyon, New Mexico (6, p. 2).

A more recent example of mankind's natural response to the beneficial effects of proper building exposure to the sun and climatic conditions is the New England Saltbox. Heating devices were placed at the center of the dwelling to capture heat given off by cooking and space heating. The architecture provided a windowed two story portion of the dwelling facing south. The north side was composed of a low sloping roof to re-direct the prevailing winds. Dark colors were also used (1, p. 11).

It was not until the 1930's that research began in the collection, storage and consumption of solar energy. Today major work has been done in the field of solar energy by such corporations as Solaron of Commerce

City, Colorado, and many others (4, p. 18).

Numerous project solar houses have been constructed throughout the United States. Some project examples would be Tucson's 'Laboratory Solar Test House' which uses air type collects. Another excellent example is 'Solar Retrofit' located in Milwaukee, Wisconsin. This project used liquid collects (6, pp. 211, 227).

Massive amounts of solar energy reaches the earth each day. If these large amounts of energy could be absorbed for man's use, it would exceed the present demand. Early mankind saw this possibility and was able to arrange the architechture and construction materials to harness this energy for his needs. In today's highly technological society much greater opportunity exists for mankind to utilize solar energy and make it work for him.

Heat Transfer

Whenever solar energy becomes a consideration for home heating either as a supplementary or primary source of heat, the home owner has to immediately contemplate heat transfer. The concept of heat transfer may be examined from three modes of heat travel: (a) Conduction, (b) Radiation, and (c) Convection. Each mode may be looked upon positively and negatively in relation to heat transfer of a solar heating unit.

When heat is gained, by proper usage of solar materials, thus increasing the efficiency of the unit and creating a positive effect. Heat that is lost, by inefficient forms of insulation or building architecture, creates a negative effect. This concept has been discussed in further detail under heat flow.

Conduction

Conduction is a process of heat transfer by which heat flows from a region of higher temperature to a region of lower temperature within a solid, liquid or gaseous medium through molecular motion. Of the three processes conduction is the only mechanism by which heat can flow in opaque solids (7, p. 15).

Radiation

Radiation is a process by which heat flows from a body at higher temperature to body at a lower temperature when the bodies are separated in space or even when a vacuum exists between them through electromagnetic waves (7, p. 16).

Convection

Convection is simply a process that transfers heat from one region to another by motion of a fluid (7, p. 18). The fluid is heated by the consumption of energy and transferred to a cooler place, where the heat is released.

All three basic methods of heat flow can be illustrated from the Colonial Home called the New England Saltbox, as mentioned earlier under the history of solar energy. This example may be described as follows: The architecture had the appearance of a low sloping roof facing in a northerly direction and windows on the first and second floors facing in a southerly direction. Heating devices were placed in the center of the dwelling to capture heat given off by cooking and space heating. It is assumed that at various times water was heated in a tea kettle and an iron skillet was used for cooking.

If this description of heat transfer can be pictured, all three concepts may be seen in operation. Radiation is released from the sun shining through the window, the skillet handle and stove. Conduction is taking place when heat is transferred from the skillet to the handle. Convection happens as air passes around the stove also as steam is released into the air.

These concepts are taking place around each home continually. Each of these concepts have a role in the heat that is lost in a building during the winter months.

Heat Flow

Heat energy is simply the motion of atoms and molecules within the molecular structure a substance. When heat is applied to a substance, motion is increased among the atoms and molecules as the substance takes on heat energy. It is at this point that heat has been transferred.

Anderson (8, p. 62) suggested two conditions for heat flow:

1. The rate of heat flow is proportional to the temperature difference between the source of the heat and the object or space to which it is flowing.

2. While the rate of heat flow is proportional to the temperature difference, the quantity of heat actually flowing depends on how much resistance there is to the flow.

A house that is heated during the winter will have greater heat transfer than in the summer, because of the temperature difference. The winter heat transfer could be decreased considerably provided a resistance is placed within the walls.

Conduction Heat Loss

The ability of a material to permit the flow of heat is called its conductance. This may have very negative effects upon a home. The opposite of conductance is resistance. A goal of construction is to retard this flow of heat. All materials have some resistance to heat flow, but those with high resistance are called insulation. The formula R = 1/C is used to calculate resistance. The higher the R-value of a material, the better its insulating properties (8, pp. 64 65). Figure 1 depicts R-values of various types of insulation. Each type of insulation is compared by a ratio of thickness and resistance. For example, when a 2x6 is used for wall construction, the rock wool-fiberglass has a R-value of 20 where as polystyrene has a R-value of 25.

Radiation Heat Flow

Radiation happens when heat flows between two bodies that are separated by space. A direct relationship exists between the effects of radiation and those of conduction and convection. Anderson (8, pp. 72, 73) pointed out:

> Radiation works together with conduction to accelerate the heat flow through walls, windows, and roofs. If surrounding terrain and vegetation are colder than the outside surfaces of your house, there will be a net flow of thermal radiation to these surroundings. Your roof will also radiate substantial amounts of energy to the cold night sky in winter.
>
> If the interior of walls and windows are colder than the objects inside a room, there will be a net flow of thermal radiation to these surfaces. A substantial flow of heat radiates to the inside surfaces of windows, which are much colder during winter than adjacent walls. This flow warms the inside surface of the glass, and more heat is pumped to the outside air because of the greater temperature difference across the glass.

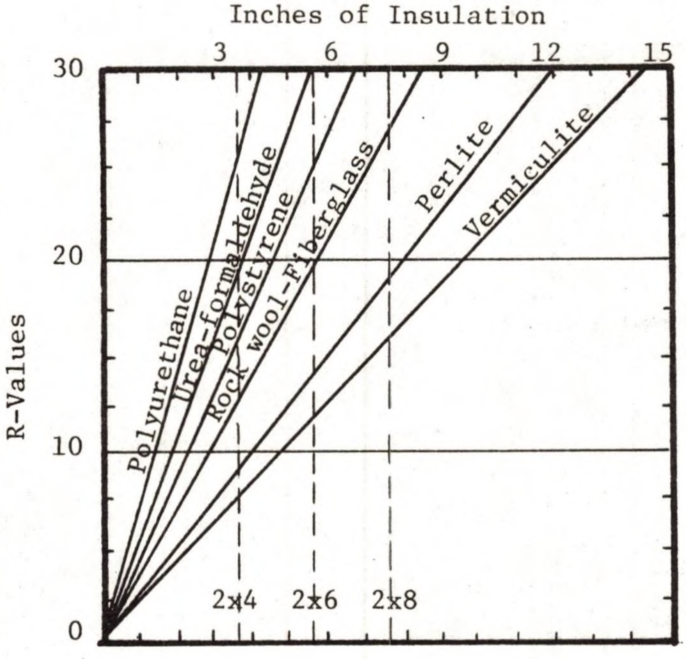


Fig. 1. Insulating effectiveness for seven kinds of insulation materials (9, p. 12).

Radiation heat flow is a factor in the consideration of heat loss from a building. It intensifies the rate of heat transferred by conduction and convection.

Convection Heat Loss

Convection was defined as the transfer of heat by a means of a fluid. Anderson (8, pp. 69, 70) described three situations in which convection heat takes place:

1. The first mode of convection heat loss occurs within the walls and between the layers of glass in the skin of the building. Whenever there is an air gap, and whenever there is a temperature difference between the opposing surfaces of that gap, natural air convection results in a heat flow across that gap.

2. The second mode includes conduction heat that flows through the exterior skin of a house works together with air movements within the rooms and winds across the exterior surface to siphon off even more heat. Since the interior surfaces of perimeter walls are usually cooler than the room air, they cool the air film right next to the wall. This cooled air sinks down and runs across the floor,

while warmer air at the top of the room flows in to take its place, thereby accelerating the cooling of the entire room.

3. A third mode uses air infiltration heat losses through openings in buildings and through cracks around the doors and windows are the primary convection losses. Small openings such as holes around outside electrical outlets or hose faucets can channel large amounts of cold air into the heated rooms. This cold air must be heated to room temperature, as must the air infiltrating around windows and doors.

A number of considerations must be weighted to avoid convection heat loss. Some examples would be location of the building, whether the building is properly insulated, if the building was properly constructed, etc.

Passive Solar Techniques

There are numerous passive solar heating techniques that can play a major role in heating a house: south-facing, greenhouse, roof monitor, a thermo-syphoning roof and insulation. Whether the house is existing or a new construction, these techniques will work toward energy conservation.

South-Facing Windows

Figure 2 illustrates this technique at point A. A double-glazed window facing in a southernly direction will serve as a collector of solar radiation. Windows facing east or west will also function as collectors during the winter. Windows must have some form of insulation at night to prevent heat loss. Drapery or shutters will function as a heat trap. Figure 2 uses an interceptor sheet of gray plastic. The air can be directed through a duct below the second-story floor to

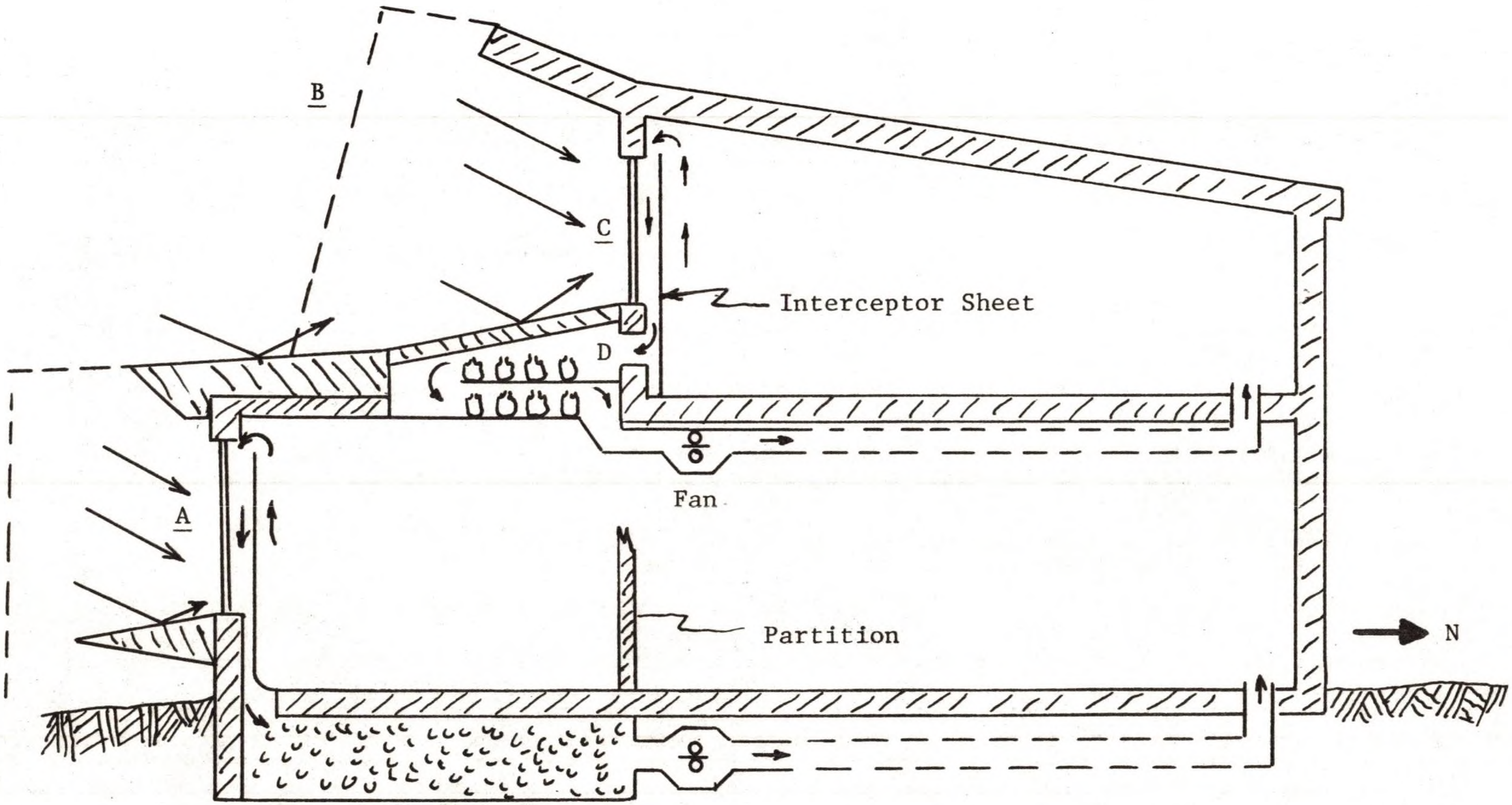


Fig. 2. Passive solar systems (10, p. 163).

heat plastic bottles filled with water. These bottles may serve as storage for solar heat. Air flow is maintained by a fan (10, p. 164).

The first floor has that same function as the second. The only difference is that air is directed into stones in place of plastic water bottles.

Greenhouse

A greenhouse may become one of the most practical techniques used by the homeowner for solar energy collection. It may also serve as a day room, sunporch and as additional room to your house (8, p. 25).

The A.I.A. Research Corporation (1, p. 25) formulated a practical use for this technique:

> A greenhouse exposes more glass (or plastic) surface area to solar heat gain than a vertical window. Conversely, more heat would be lost at night if no provision is made to use the heat during the day or to insulate the glass at night.
>
> Because the greenhouse is attached to a house, however it is a simple matter to close it off from the house proper at night, letting the temperature drop in the greenhouse without increasing heating requirements of the house.

Figure 2 at point B has provided an illustration of a greenhouse serving as a collector.

Roof Monitor

Roof monitors are skylights or raised roof sheds that are designed to control heat gain, natural light, and/or ventilation. The primary purpose of roof monitors is cooling rather than heating, because they are at such a high location, and the sun angle during the winter is low (6, p. 25). As a result little heat is gained through roof monitors. It becomes an effective means for cooling during the summer, as heat naturally raises. Figure 2 at point C depicts this concept.

Thermo-syphoning Roof

Thermo-syphoning is a passive solar technique which makes use of trapped heat in walls and roof structures to heat a specific room. Figure 2 at point D demonstrates this concept. The principle of thermo-syphoning is simply the natural rise of heated fluids to a place of use or storage. (1, p. 25) The A.I.A. Research Corporation (1, pp. 25, 26) spoke of three cases that demonstrate this technique:

1. One thermo-syphoning concept which has found application in traditional as well as solar design is the use of solar heat trapped in air spaces in walls and roofs. When the trapped air temperature exceeds the temperature of the internal building space it can be drawn off by direct venting or forced air duct arrangements.

2. A more effective variant of the preceding concept is one where the external surface or internal and external wall or roof surface are transparent. The heated air trapped between the building surfaces can be used because it will usually be hotter than the temperature of the occupied space.

3. In a further elaboration, the building envelope is also used as storage. A glass wall is placed over an absorbing material. The air space between the glass wall and the absorbing material is vented to the interior at the top of the wall or ducted to rock storage elsewhere in the building. A cold air return must be located at the bottom of the collector so that a thermo-syphoning arrangement can be used to facilitate air circulation.

This technique provides a practical means, with minimum additional cost to construction, to maximize use of solar energy.

Insulation

Insulation functions in the form of passive solar heat by retarding heat flow. As a result heat is accumulated faster and more efficiently. This passive technique needs methods for collection of solar energy.

Figure 1 illustrates the resistive qualities of various types of insulation. Insulation with the highest resistive value may not always be used, although that would be the most desirable. A situation involving an existing house needing insulation to decrease its heat transfer from inside to outside could not use an insulation that came in a solid form. That would be inappropriate. It would be necessary to have a form of insulation that could be poured.

The primary concern is whether the house has sufficient insulation or not. A local dealer should be contacted to appraise the house's condition if insulation is not proper.

Basic Concepts of Active Solar Systems

The basic concepts behind solar heating systems are the conversion of solar energy into thermal energy and the application of directly or indirectly heating a building (11, p. 8). Typically, active solar heating is a general concept that includes two specific types of solar systems. These are the liquid-type and air-type solar heating systems.

Figure 3 makes reference to simplified active solar system. Six generic components are illustrated that describe the operation of an active solar system: collector, storage, distribution, transport, auxiliary energy system and controls. Each of these components may be used in any solar system (1, p. 17).

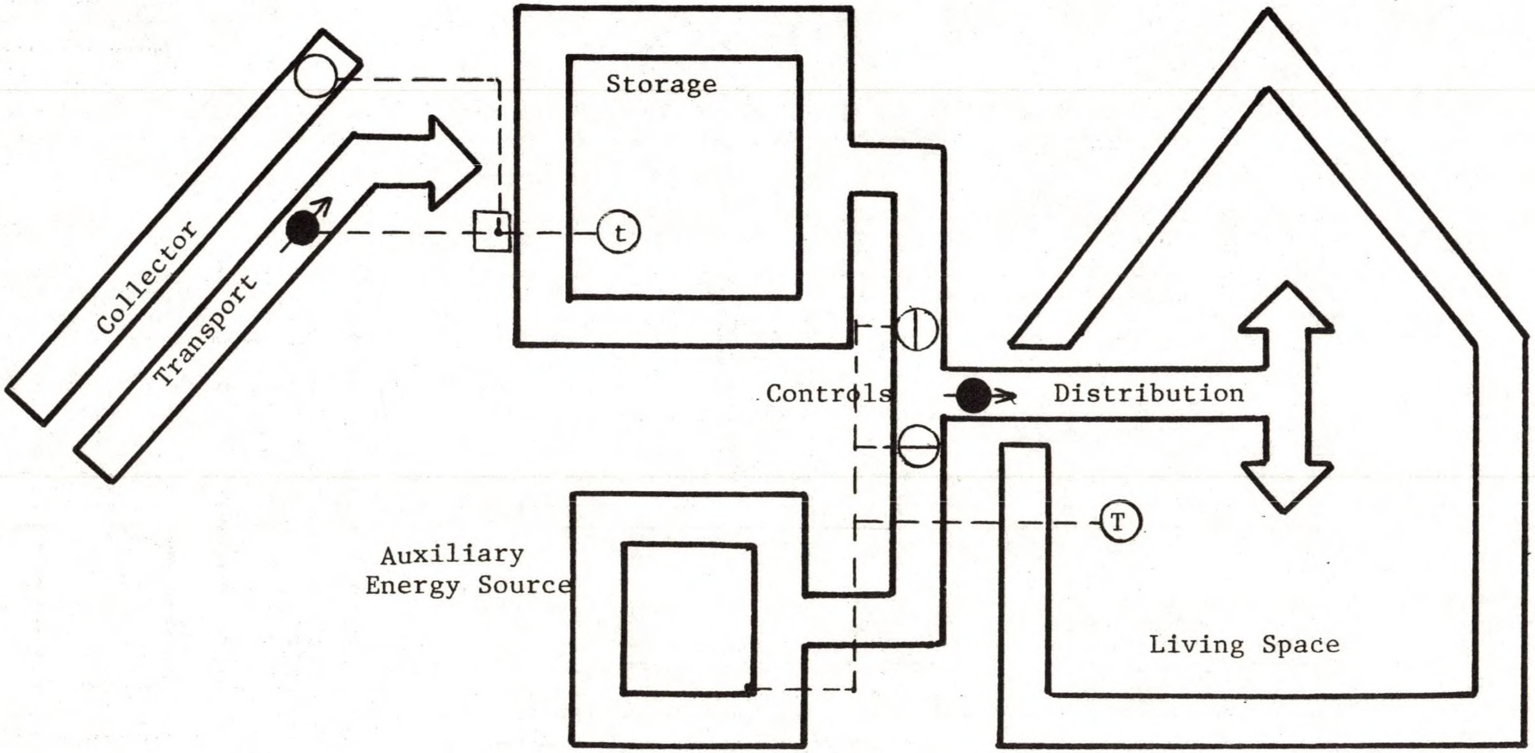


Fig. 3. Simplified diagram of a solar heating system (1, p. 18).

The essential gathering of solar energy begins in the collector. The heat energy is transported by means of a fluid under a liquid or air-type solar system. The heat energy is then either stored or distributed throughout the house. Controls serve to monitor when sufficient heat has been distributed. The auxiliary energy unit is used only during prolonged cloudy days, when there is a lack of solar energy (1, p. 17).

Liquid-Type Solar System

After the discussion of active solar system, including both active air and active liquid solar system, the researcher has first considered the liquid-type. This employs liquid as means of heat transfer.

There are some definite advantages in selecting liquid-type solar heating (4, pp. 12, 13). These advantages are:

1. It permits the design of a more versatile system. Liquid-type can be used for space heating, heating domestic water as well as your swimming pool, and cooling your home.

2. Water is a better heat transfer medium than air.

3. Pipes that carry water from the collectors to storage are small. This has provided for a compact layout of piping within the limits of the building design.

4. There is a wider selection among makers of liquid-type solar collectors than firms producing air-type collectors.

5. There are more liquid solar systems installed then air solar systems.

Figure 4 depicts the liquid-type solar system. The top half has delineated the liquid-type functioning solely for space heating. The lower half demonstrated the heating of both space and domestic water.

The first thing to be noticed in the upper drawing is the collector. Water is pumped to the lower end of the solar collector. Then as the water is heated by the sun's energy, it raises to the top of the collector. It then flows through the header pipe connected to the outlet of the panel and back into the coils of the heat exchanger. The heat may at this time be stored or put into the system for space heating. If heat is stored, it becomes necessary to use this heat when cloudy weather sets in or during the night hours. The auxiliary heater using conventional fuel is used only when there is a prolonged spell of cloudy weather (4, p. 16).

Two alternative methods have been shown to distribute the heat throughout the house. If the hydronic system is used with hot water pipes throughout the house, then the hot water that is heated in the collectors circulates through the house. Provided the house has forced air system, solar heated water is circulated through coils. Air is blown across these heated coils and distributed to various parts of the house (8, p. 16).

The lower half of figure 4 differs from the upper half only in the area of domestic water heating. An auxiliary heater is installed for a safeguard against prolonged cloudy weather. Water is circulated from the storage tank through the auxiliary water heater (the heater is by-passed unless needed) and throughout the house for normal usage. Water returns to the storage tank cold (4, p. 18).

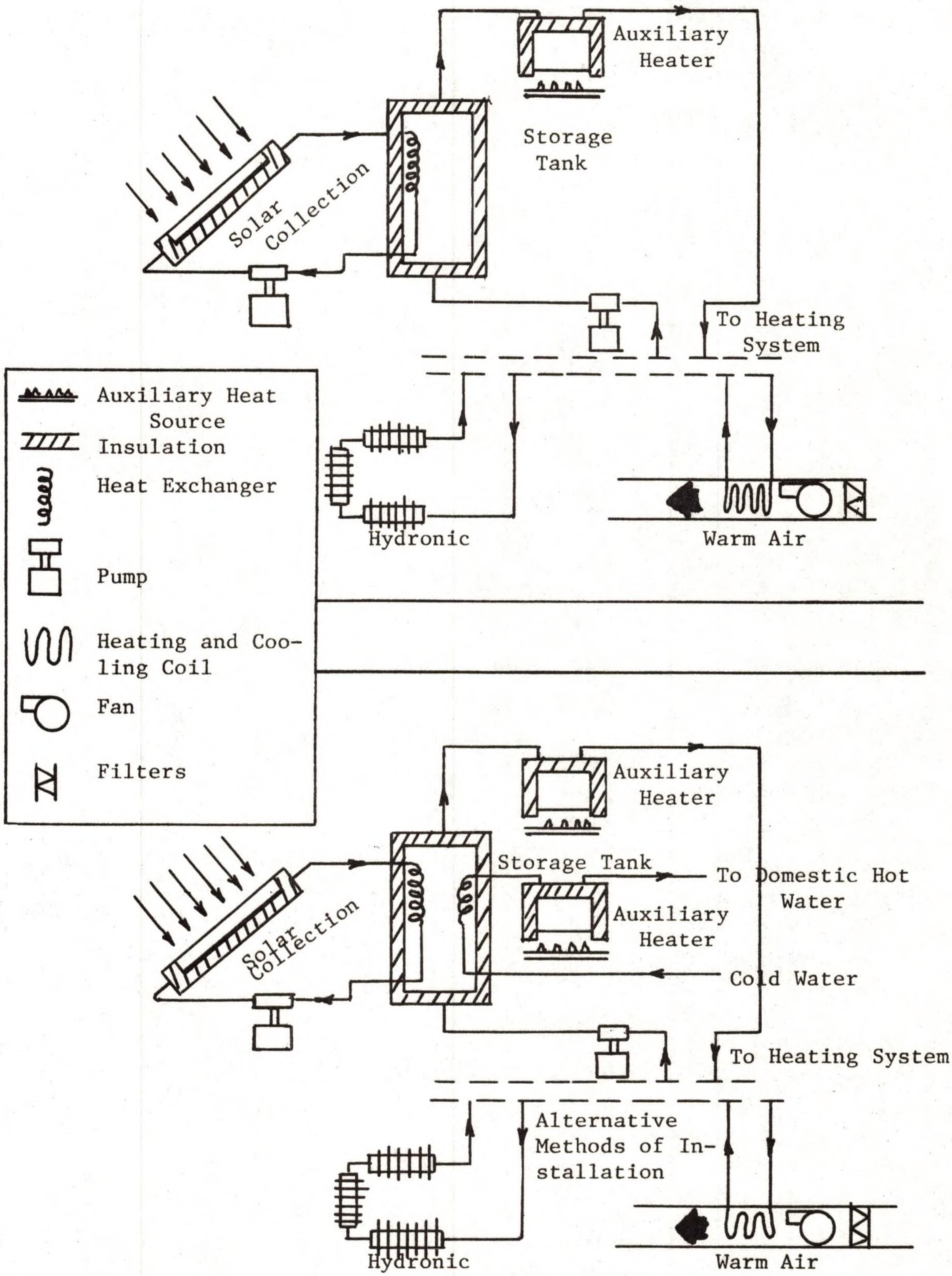


Fig. 4. Designs for liquid-type solar heaters (4, p. 17).

Air-Type Solar System

Whenever an active solar system has been discussed, the tendency is to draw a comparison between the liquid-type and air-type solar systems. The air-type system offers some definite advantages. This is especially for those living in the colder areas. This type employs air as a means of heat transfer.

The A.I.A. Research Corporation (1, p. 35) formulated advantages and disadvantages to the air-type system. The major advantages are:

1. Capital cost tends to be lower than a water system of the same capacity.

2. There is no problem with corrosion, rust, clogging or freezing.

3. Air leakages does not have the severe consequences of water leakage.

4. Domestic hot water supply is not subject to contamination by leakage from heat storage, as in the water system.

The major disadvantages of an air-type solar heating unit are:

1. Ductwork risers occupy usable floor space and must be aligned floor to floor.

2. Air, having a lower thermal storage capacity than water, requires correspondingly more energy to transfer a given amount of heat from collector to storage, and from storage to occupied spaces.

3. Air collectors and storage may need frequent cleaning to remove deposits of dust (filters may solve this problem).

4. Air systems require a much larger heat exchange surface than liquid systems.

Air heating system by solaron

Solaron is a corporation experienced in the manufacture of solar systems. They have offered an example that has described the air-type system. Figure 5 illustrated the operation of this type of solar system.

Air is drawn through the collector array (1) and heated to temperatures averaging between 120 degrees F. and 150 degrees F., depending upon weather conditions surrounding the solar system. The sun-heated air passes through a conventional duct containing an air-to-water exchanger (5), which heats the water in a domestic preheater tank. Water from the preheater tank flows into a conventional domestic hot water heater, which adds energy (conventional) when required. Most of the solar hot air is pumped through a Solaron air-handling unit (3) and then through a conventionally fueled auxiliary heater via ductwork and into various rooms. The returned air goes to the solar collectors. A large storage bin (2) filled with carefully washed stones. They are washed to prevent dust from blowing into the house (4, pp. 18-20).

Air heating system by National Energy Corporation

This corporation provides another example of the air-type solar heater. This example closely resembles the system under investigation in this study.

Figure 6 depicts an air-type solar system designed by the National Energy Corporation (12, p. 6). They have described each process of the system as it has functioned during operation:

1. Heating from collector - Return air from the building is drawn through the collectors into the air handler - from

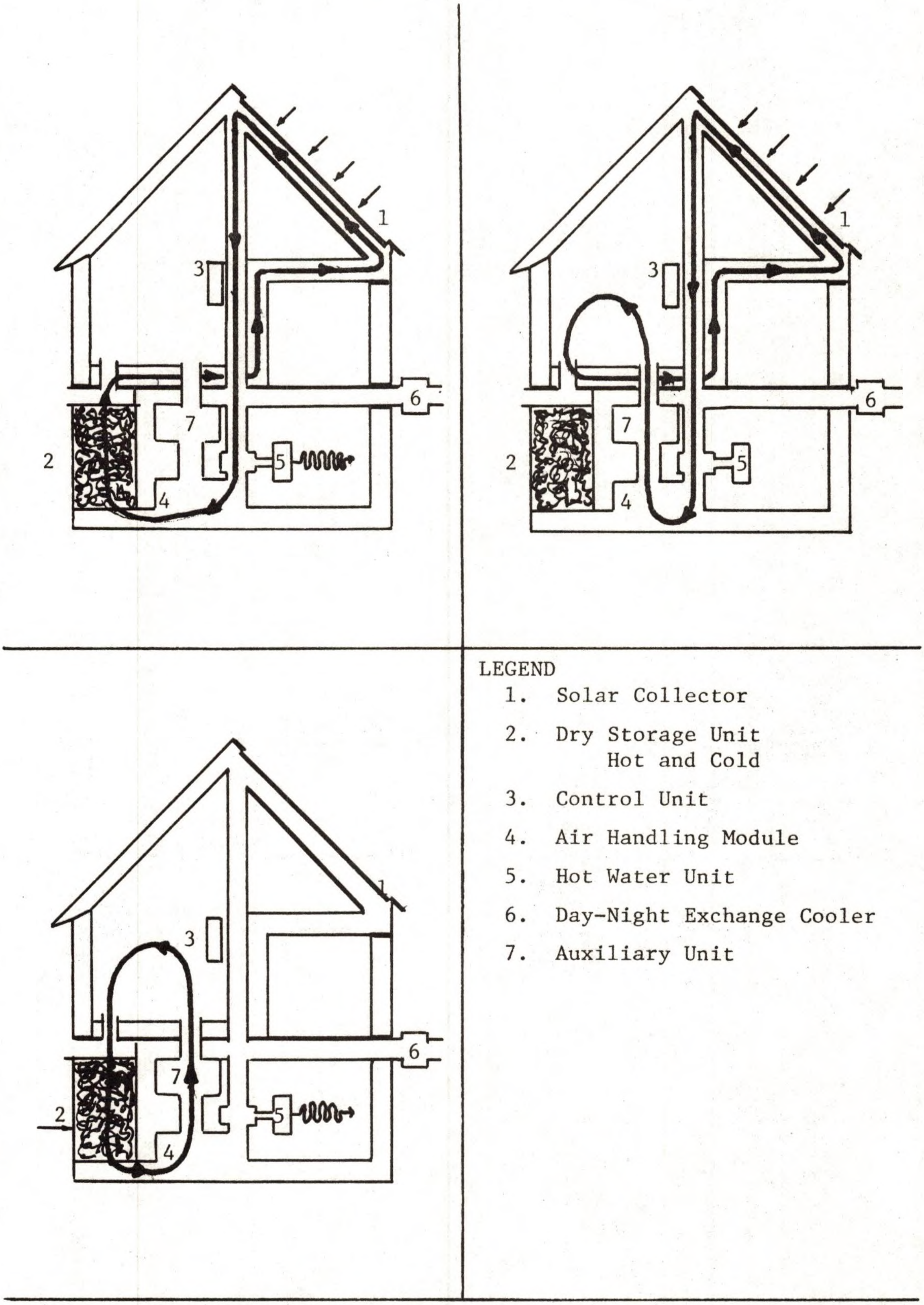
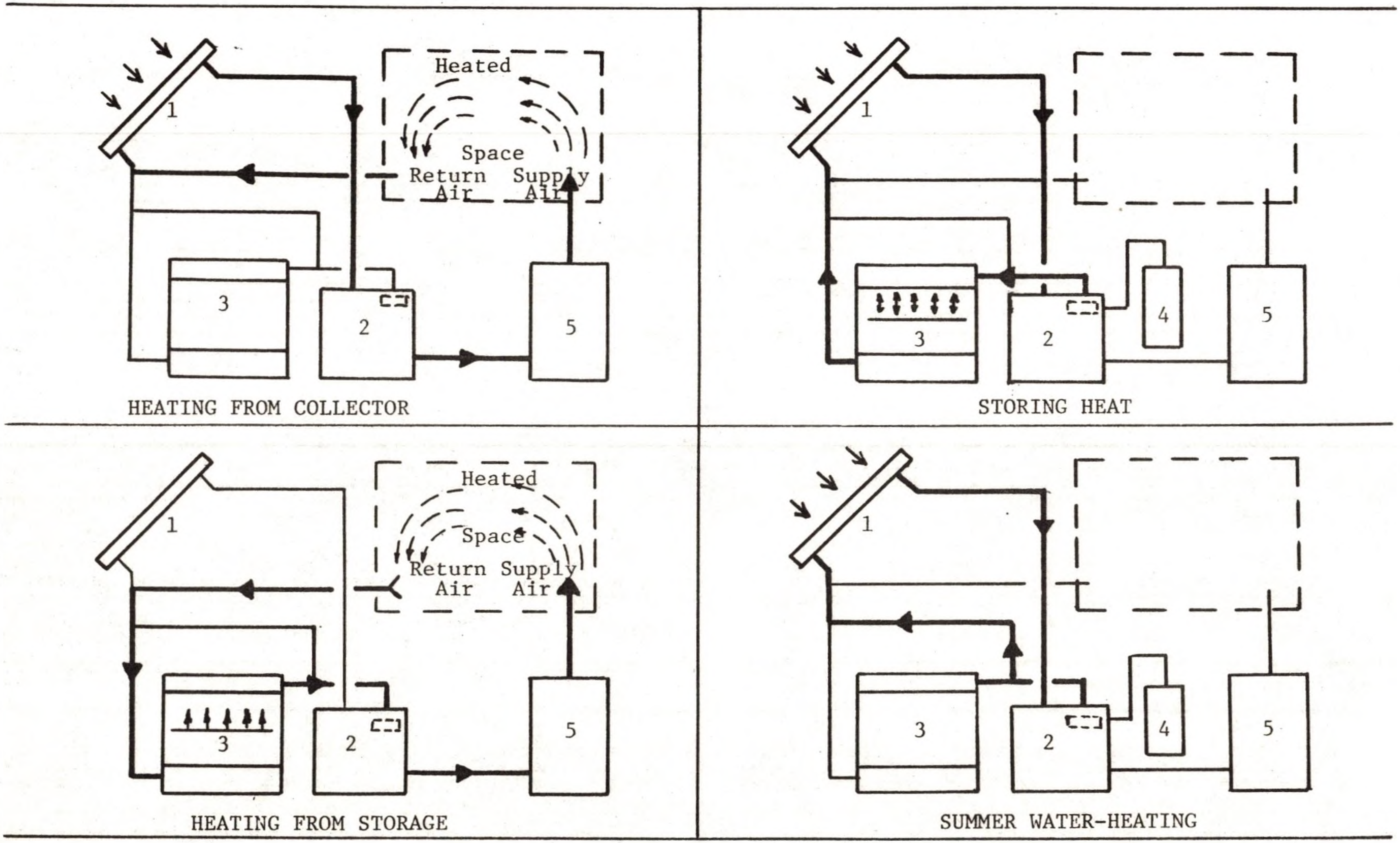


Fig. 5. Design for air-type solar heater (10, p. 125).



KEY: 1. Collector 2. Air Handling 3. Heat Storage Unit 4. Domestic Hot Water Preheater & Tank 5. Furnace

Fig. 6. Solar air heating system (12, p. 2).

the air handler it passes through the auxiliary furnace and back into the heated areas of the building. The air is normally heated to 115 to 155 degrees in the collectors. Motorized dampers in the air handler unit automatically position themselves depending on heating requirements and solar energy available.

2. Storing heat - When the thermostat in the building is satisfied, the automatic control system re-positions the dampers so that the heated air passes into the heat storage unit. The air passes through the heat storage unit where the heat is stored and cold air is returned to the collectors where it is heated and the cycle is repeated.

3. Heat from storage - When the building thermostat calls for heat, at night or on cloudy days when solar energy is not available, the automatic control system positions the dampers in the air handling unit so that return air from the building is drawn through the heat storage unit where it is heated and then passes through the auxiliary furnace and into the building. At any time when there is not enough solar heat to satisfy the building requirements, the auxiliary heating unit will be turned on automatically.

4. Summer water heating - during the summer when the building requires no heat, the air is circulated through the collectors where it is heated and is drawn into the air handler unit where it passes the domestic hot water coil. The air is then circulated back to the collectors where it is heated again and the cycle is repeated. Domestic hot water is circulated through the coil where it is heated by the air.

Similarities may be seen between each system. These figures have described the story of the operation of air-type solar heating.

Economics and Solar Energy

Economics has prevented widespread utilization of solar energy; at present, cost is still a major obstacle. It is probable that this cost will be reduced as the need for solar energy increases.

Cost may be established by use of the term degree day. This involves a simple multiplication: the average 24 hour temperature in degrees below $65° - \bar{T} \times 1$ = the degree day value of any specific day.

For example, if the average temperature on January 25 is 10°F, this is a 55 degree day (10, p. 85). This figure is calculated with furnace input and solar installation cost to determine economics.

Svard, Somerville and Mathsen (13, p. 13) concluded: Conventional heating systems and solar heating systems are economically competitive on a twenty year basis. Hyman (2, p. 35) also suggested that the economics are not yet compelling; for widespread acceptance, solar systems require some government subsidy.

Lucas (4, p. 7) proposed:

> It's only logical to assume that fuel costs will continue to rise. Studies made by financial experts indicate that if you save $45 a month in fuel bills, and the annual rise in fuel costs averages 5%, and if the interest rate you pay on your solar installation is 10%, you can afford to invest about $4,300 in your solar heating equipment. At the end of ten years, it will be paid for.

In the future, consumption of solar energy will continue to increase resulting from increased cost of fossil fuels (3, 4, 5, 10, 13). The solar installation cost will decrease as the shift to solar energy increases. Svard, Somerville, and Mathsen (13, p. 13) spoke of the economics involved in solar heating and their overall resource impact (potential doubling of resource life) make them look very attractive for future residential heating application.

Legislation programs on the national, state and local levels are promoting solar energy development. President Carter's goal of 2 1/2 million solar homes by 1985 looks modest. It is possible, if the tax credits pass, to have an 11 million installation by 1985 (14, p. 24).

Wilhelm (15, p. 397) quoted Dyson, a resident of the Institute for Advanced Study in Princeton:

> The only limits to the technological growth of a society are internal . . . A society has always the option of limiting its growth either by conscious decision or by stagnation or by disinterest. A society in which these internal limits are absent may continue its growth forever.

This quote exhorts our nation to continue in its efforts toward total utilization of the sun's power. Economically, this nation cannot afford to be disinterested in solar energy.

Summary

Throughout history practical applications in solar energy have provided an example for this technological society. Ancient Indian civilizations were able to design their buildings to make maximum use of the sun's rays to heat their homes. They have also built into their homes from materials that had a capacity for storage of solar energy. This heat energy was released during the night hours. These passive solar techniques have demonstrated a great deal of effectiveness for heating and cooling. Truly, this effectiveness may be multiplied many times over in today's highly technological society.

Present day solar systems serve mankind by both passive and active solar techniques. Passive solar systems are built into the architecture of the home to make solar collection a natural process. Some examples of passive collecting techniques are south-facing windows, the greenhouse, roof monitor and a thermo-syphoning roof. A further step beyond collection involves another passive technique called heat retention in the form of insulation. By using the proper insulation and construction techniques, a building may have a resistance to heat transfer from inside to outside.

Active solar system implies the use of mechanical means to transfer heat once it has been collected. Active solar system is made up of two types of systems. These are liquid-type and air-type solar systems.

The liquid-type solar system uses liquid as the means of heat transfer. This type has the advantage of having a wider selection among makers of liquid-type solar collectors providing opportunity for reduced cost.

The air-type solar system uses a gas as the means of heat transfer. It has the primary advantage of not freezing in cold northerly climates. Either system that is used increases the collection process beyond passive solar techniques of solar energy.

Economics for the present is not yet compelling. Installation costs of a solar system continue to prevent wide spread utilization of solar energy. But as fossil fuel costs continue to increase and the growth in resource impact of solar systems uses the coming years look very attractive for future residential heating application. Whether its a new structure or an existing building that has undergone retrofitting both develop similar types of problems. A homeowner must consider what is the most practical and efficient method of incorporating solar systems to his individual home.

CHAPTER III

METHODOLOGY

Introduction

The intent of this chapter is to describe the methods and procedures of investigation conducted in this study. This chapter is composed of the following topics: introduction, type of research, method of data collection and sources, data recorded, treatment of data, and other variable factors.

Type of Research

The research employed in conducting this study was the descriptive type. Data was compiled by the researcher by personal interviews to collect the desired records. This approach was considered the most appropriate when deriving information from specific locations.

Method of Data Collection and Sources

To conduct this study, the researcher was actively involved in three major sources of information: the Chester Fritz Library, Northern States Power, and the University of North Dakota Geographical Weather Station.

The Chester Fritz Library, with its inter-library loan service, provided the reading sources for Chapter II. Sources were located by the library card catalog, the National Solar Heating and Cooling Information Center, and from bibliographies contained in books.

The Northern States Power Company had the necessary records concerning gas consumption needed for this study. This data were collected on prepared forms. Prior to the collection of this data, the researcher scheduled an interview with Mr. Linfoot, the owner of the solar heating unit under investigation. The researcher explained his interest in investigating Mr. Linfoot's conventional and solar heating system. With the consent of Mr. Linfoot, the gas consumption records were obtained from Northern States Power Company that have been used in this study.

The University of North Dakota Weather Station furnished the temperature readings that coincided with the gas consumption records. The author acquired these records at the Geography Department at the University of North Dakota, and obtained the readings necessary for this study.

Factors Involved

The factors involved in the analysis of a supplementary air-type solar heating were two-fold: (a) to obtain gas consumption records for three seasonal years, and (b) to obtain temperature records for three seasonal years.

Gas consumption records that were acquired involved data from three seasonal years. This data was on the basis of cubic feet of natural gas consumed.

The three seasonal years were divided into two parts. Part one dealt with pre-test data and included seasons one and two. Season three was included under part three and dealt with post-test data. Table 1 explains the periods in which each seasonal year took place.

TABLE 1

DEFINITION OF SEASON LENGTH

	From	Through
Season One	8 - 25 - 75	4 - 26 - 76
Season Two	8 - 24 - 76	4 - 26 - 77
Season Three	8 - 26 - 77	4 - 28 - 78

Temperature records that were acquired included each seasonal year referred to in Table 1. The temperature readings were collected on the basis of degrees Fahrenheit.

Data Recorded

Two forms were prepared for collection of data need for this study. Examples of these forms are given in Appendix A. The titles for these forms are as follows: (a) temperature, and (b) gas consumption. The body of the forms were arranged so that seasonal years and months were in order to outline the collected data. Appendix A has examples of each form.

Treatment of Data

After collection of the data, a mathematical analysis was conducted in terms of the degree day and efficiency of the furnace. This analysis was related to both pre-test and post-test data. The data included fuel consumption and average temperatures. At this point the researcher established if there was a difference from one heating season to another in terms monthly and seasonal year data based on fuel consumption and average temperature. This comparison is broken down into an investigation of pre-test data only.

A further comparison involves an investigation between pre-test and post-test data by seasonal years. This comparison was based on fuel consumed and average temperature.

A further investigation by the researcher involves an analysis of the calculated monthly energy value in terms of least squares method. The purpose of this analysis has been to determine how far each season varies from the other in terms of energy consumed.

An evaluation was conducted on the amount heat transfer in pre-test and post-test data. This was accomplished by comparing the maximum solar efficiency with the efficiency generated from the heat transfer figures. An economic evaluation was made on the basis of a percentage actual solar efficiency and current gas prices.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

Intent of Study

The nature of this study was to consider the impact of air-type solar heating units on conventional heating systems and the combined effect of an air-type solar heating system and a conventional heating system. Data were analyzed in terms of pre-test data for season one and season two, and post-test data, season three.

Type of Analysis

The analysis of the data was computed by tabulating gas consumption and temperature rates on a monthly and seasonal basis. This data was calculated in terms of the degree day and furnace efficiency to produce an energy value. The data was presented in the form of tables, figures and narrative descriptions.

A further analysis of the data was conducted to analyze the calculated monthly energy value in terms of the least squares method.

Data Collected for Analysis

To enable the researcher to analyze a supplementary air-type solar heating unit operating in conjunction with a conventional forced air heating system, a series of tables have been prepared to illustrate data analysis.

Tables 2, 3, and 4 contain temperature values of the three seasonal years. These seasonal years have been broken down into eight gas pay periods. The dates for each pay period are given at the top of each list.

Totals and averages for the pay periods are found at the bottom of each table. An overall total and average for the season has also been noted to aid in the analysis.

Table 5 presents the data of gas usage for each seasonal year. The daily gas usage has not been given because a monthly total was the only available data. Dates have been given for each season as well as the individual pay periods within a particular season. The totals given were also necessary for reason of a comparison.

A general observation of Table 5 has defined a smaller consumption of gas during post-test data as compared to pre-test data. This difference has been compared in detail, as it relates to the temperatures found in Tables 2, 3 and 4, later in this chapter.

Domestic Water, Energy Calculations and Solar Energy

Energy calculations were done using domestic water energy within total energy consumption. The results of such calculations are illustrated in Figure 7. In a general observation of this graph, it is difficult to determine how each season relates to the other. This is due to the effects of domestic water upon decreasing degree day value in the fall and spring.

Figure 7 graphically depicts how each season relates to the other, based on the energy value and domestic water for each season. Figure 7 also indicates that season one and two have demonstrated similar

TABLE 2

TEMPERATURE VALUES FOR SEASON ONE (8-25-75 THROUGH 4-26-76)

Average Daily Temperature/Pay Period, Fahrenheit

8-25-75 Through 9-23-75	9-24-75 Through 10-22-75	10-23-75 Through 11-20-75	11-21-75 Through 12-25-75	12-26-75 Through 1-25-76	1-26-76 Through 2-23-76	2-29-76 Through 3-24-76	3-24-76 Through 4-25-76
67	51	42	24	9	-7	41	31
59	56	38	19	23	-1	38	32
60	58	40	13	31	24	36	35
71	60	36	8	32	15	20	43
70	61	40	8	23	19	7	40
67	59	34	13	24	30	-4	39
69	51	38	18	23	7	6	39
60.2	44	45	23	7	9	25	45
59	58	44	19	-5	9	7	43
60	58	46	5	-15	-8	-5	42
59	63	47	3	0	-5	15	40
54	64	51	1	-11	10	10	44
53	58	58	13	-18	25	14	45
55	77	57	33	-11	29	21	42
51	72	57	11	-8	37	16	47
61	58	47	7	8	22	2	51

TABLE 2--Continued

Average Daily Temperature/Pay Period, Fahrenheit

8-25-75 Through 9-23-75	9-24-75 Through 10-22-75	10-23-75 Through 11-20-75	11-21-75 Through 12-25-75	12-26-75 Through 1-25-76	1-26-76 Through 2-23-76	2-29-76 Through 3-24-76	3-24-76 Through 4-25-76
63	43	43	19	16	12	18	50
50	47	33	26	19	28	14	39
47	53	29	27	10	20	21	49
53	49	31	20	6	26	15	58
63	45	25	4	8	29	21	60
63	42	18	5	-5	30	5	48
60	46	29	15	1	34	24	58
66	45	36	-10	20	31	36	56
54	54	41	1	14	29	31	40
50	52	37	5	11	22	25	43
46	55	37	-12	20	18	9	45
50	47	35	-1	7	17	33	42
56	49	29	29	20	35	44	45
56			20	18		35	48
			20	9			49

TABLE 2--Continued

Average Daily Temperature/Pay Period, Fahrenheit

	8-25-75 Through 9-23-75	9-24-75 Through 10-22-75	10-23-75 Through 11-20-75	11-21-75 Through 12-25-75	12-26-75 Through 1-25-76	1-26-76 Through 2-23-76	2-29-76 Through 3-24-76	3-24-76 Through 4-25-76	
				12				46	
				21					
				14					
				12					
T	1752.2	1580	1143	445	276	546	580	1434	7756.2
A	58.41	54.48	39.41	12.71	8.9	18.83	19.33	44.81	969.5

TABLE 3

TEMPERATURE VALUES FOR SEASON TWO (8-24-76 THROUGH 4-25-77)

Average Daily Temperature/Pay Period, Fahrenheit							
8-24-76 Through 9-22-76	9-23-76 Through 10-21-76	10-22-76 Through 11-21-76	11-22-76 Through 12-26-76	12-27-76 Through 1-25-77	1-26-77 Through 2-23-77	2-29-77 Through 3-24-77	3-25-77 Through 4-25-77
77	42	23.0	20.6	3.1	5.5	21.7	39
79	47	23	15.9	-10.8	-10.8	22.4	37
76	49	26	29.8	-8.0	-13.5	20.8	47
73	44	24.5	15.4	-17.7	-2.6	9.5	47
60	42	22.7	-3.6	-17.0	0.1	9.4	42
62	51	27.8	-0.4	-1.8	2.2	12	29
65	59	48.7	-0.1	1.4	9.7	11	32
68	69	43.4	4.4	2.1	17.8	19	40
57	64	41.8	4.8	-5.6	15.8	22	36
73	56.5	37.6	-9.4	-3.1	8.6	20	38
73	70	47.7	5.5	1.3	-2.6	15	33
60	59	44.6	13.7	-7.6	-9.1	26	27
70	37	34.6	5.0	-17.0	10.8	35	34
73	31	29	-4.9	-19.4	26.9	45	36
77	35	38.2	-5.4	-17.9	28.4	42	44
55	48	32.5	-6.2	-18.1	34.5	36	60

TABLE 3--Continued

Average Daily Temperature/Pay Period, Fahrenheit							
8-24-76 Through 9-22-76	9-23-76 Through 10-21-76	10-22-76 Through 11-21-76	11-22-76 Through 12-26-76	12-27-76 Through 1-25-77	1-26-77 Through 2-23-77	2-29-77 Through 3-24-77	3-25-77 Through 4-25-77
54	42	17.9	4.3	-19.5	37.1	34	60
64	50.5	29.5	-6.4	-4.0	33.9	36	49
68	62	34.5	13.9	-14.8	23.5	40	51
73	52.5	20.3	-2.2	-18.2	11.9	39	47
66	49.5	13.9	8.9	-21.2	5.1	33	52
54	50.5	25.8	31.3	-17.0	23.2	30	59
57	38	23	24.3	1.8	24.1	35	59
59	32.5	24.2	30.9	15.9	18.2	34	68
70	28	28.8	26.9	15.9	14.9	28	58
69	22.5	28.7	28.8	14.9	18.1	29	44
65	29.5	35.1	14.2	15.9	29.0	27	49
54	38.8	39.1	-1.4	28.2	28.3	18	47
45	31.2	31	8.5	22.1	26.4	38	55
49		26.6	15.3	21.2			54
		26.4	3.9				45
			15.6				53

TABLE 3--Continued

	Average Daily Temperature/Pay Period, Fahrenheit								
	8-24-76 Through 9-22-76	9-23-76 Through 10-21-76	10-22-76 Through 11-21-76	11-22-76 Through 12-26-76	12-27-76 Through 1-25-77	1-26-77 Through 2-23-77	2-29-77 Through 3-24-77	3-25-77 Through 4-25-77	
				8.9					
				1.8					
T	1945	1331	950.7	337.1	-94.9	415	787.8	1471	5198.1
A	60.78	45.9	30.67	9.63	3.16	14.32	27.17	45.96	649.8

TABLE 4

TEMPERATURE VALUES FOR SEASON THREE (8-26-77 THROUGH 4-28-78)

Average Daily Temperature/Pay Period, Fahrenheit

8-26-77 Through 9-26-77	9-27-77 Through 10-26-77	10-27-77 Through 11-27-77	11-28-77 Through 12-28-77	12-29-77 Through 1-29-78	1-30-78 Through 2-27-78	2-28-78 Through 3-29-78	3-30-78 Through 4-28-78
65	55	51	8	8	-3	0	41
59	53	49	20	-9	-5	-1	44
62	48	55	31	-11	-13	3	29
61	52	54	18	5	-10	-3	30
67	46	50	8	10	-3	-1	32
64	46	45	-5	3	0	2	37
52	49	40	3	0	-16	0	42
58	53	40	-1	4	-8	11	46
62	42	35	-5	6	2	19	34
60	45	47	-7	3	9	32	39
58	38	53	-5	-8	7	32	41
58	41	52	-17	-16	1	29	40
58	47	42	-18	-14	-3	22	40
61	43	30	1	-6	2	23	37
58	41	27	12	2	4	18	33
58	46	27	12	3	8	22	38

TABLE 4--Continued

Average Daily Temperature/Pay Period, Fahrenheit							
8-26-77 Through 9-26-77	9-27-77 Through 10-26-77	10-27-77 Through 11-27-77	11-28-77 Through 12-28-77	12-29-77 Through 1-29-78	1-30-78 Through 2-27-78	2-28-78 Through 3-29-78	3-30-78 Through 4-28-78
58	58	21	19	0	4	18	42
56	52	30	27	-1	4	19	41
60	42	24	31	-15	7	31	47
62	49	31	34	-13	1	32	47
68	51	32	23	-7	11	33	36
64	47	32	14	-8	7	38	34
60	52	22	10	-10	7	36	39
54	49	20	0	-6	20	26	47
52	43	22	6	3	24	23	47
51	36	12	5	20	22	32	51
57	42	0	0	11	6	38	50
56	49	4	-9	9	2	39	54
55	54	-5	-11	-13	8	37	58

TABLE 4--Continued

Average Daily Temperature/Pay Period, Fahrenheit

	8-26-77 Through 9-26-77	9-27-77 Through 10-26-77	10-27-77 Through 11-27-77	11-28-77 Through 12-28-77	12-29-77 Through 1-29-78	1-30-78 Through 2-27-78	2-28-78 Through 3-29-78	3-30-78 Through 4-28-78	
	60	58	-3	3	-13		31	61	
	56		2	13	-9				
	53		8		-9				
T	1883	1427	949	220	-68.97	95	641	1257	6403.0
A	58.84	47.57	29.66	7.1	2.16	3.28	21.37	41.9	800.4

TABLE 5

GAS CONSUMPTION VALUES FOR THE THREE SEASONAL YEARS

Season One 8-25-75 Through 4-26-76	Season Two 8-24-76 Through 4-26-77	Season Three 8-26-77 Through 4-28-78
8-25-75 Through 9-24-75 57 CCF	8-24-76 Through 9-22-76 51 CCF	8-26-77 Through 9-26-77 37 CCF
9-24-75 Through 10-22-75 68 CCF	9-23-76 Through 10-21-76 80 CCF	9-27-77 Through 10-26-77 60 CCF
10-23-75 Through 11-20-75 119 CCF	10-22-76 Through 11-21-76 152 CCF	10-27-77 Through 11-27-77 111 CCF
11-21-75 Through 12-25-75 225 CCF	11-22-76 Through 12-26-76 255 CCF	11-28-77 Through 12-28-77 236 CCF
12-26-75 Through 1-25-76 224 CCF	12-27-76 Through 1-25-77 246 CCF	12-29-77 Through 1-29-78 274 CCF
1-26-76 Through 2-23-76 199 CCF	1-26-77 Through 2-23-77 195 CCF	1-30-78 Through 2-27-78 204 CCF
2-24-76 Through 3-24-76 197 CCF	2-24-77 Through 3-24-77 135 CCF	2-28-78 Through 3-29-78 132 CCF
3-24-76 Through 4-24-76 100 CCF	3-25-77 Through 4-25-77 102 CCF	3-30-78 Through 4-28-78 80 CCF
1219 CCF	1216 CCF	1134 CCF Total Gas Consumption

Note: Total gas consumption for domestic water and heating

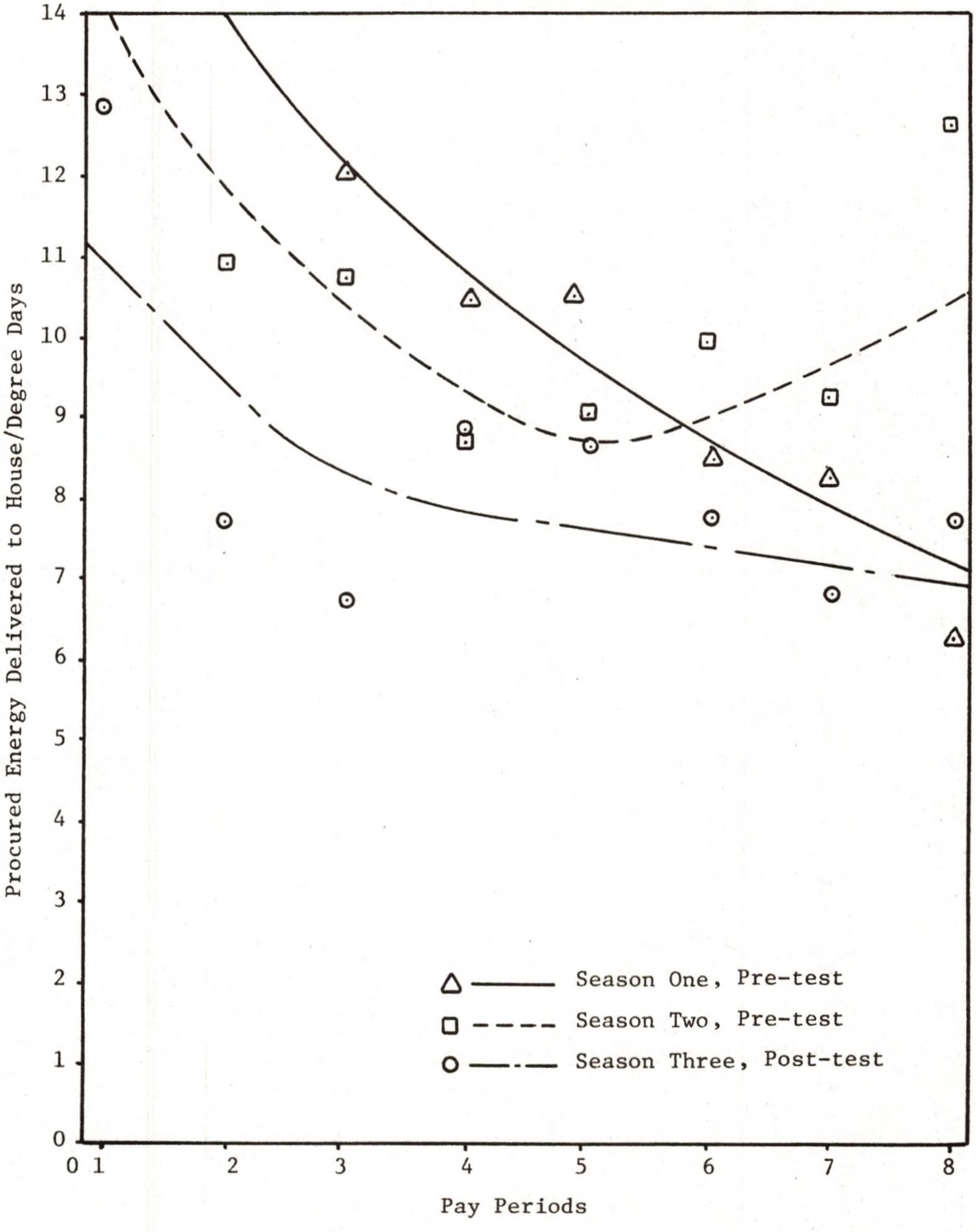


Fig. 7. Seasonal energy consumption per season with domestic water.

characteristics during the fall and winter months. In spring months, periods 7 and 8, a separation was noted. This shows a definite change taking place in the weather conditions.

Season three has demonstrated that less energy was consumed. This may be seen easily during the fall months, however, during the winter months, this energy savings is reduced to a slight amount. For example, in comparision of season two and three, little if no difference can be noted in the winter. During the spring a greater difference may be seen.

As a result of these unclear effects, the author has chosen to exclude domestic water throughout the remainder of Chapter IV.

Solar Energy Usage

In the following calculations, as given in Tables 6, 7 and 8, the domestic water energy value was excluded. This excluded value was determined simply by referring to the energy consumed during the summer months for heating domestic water. This value was then subtracted from the winter energy values. Each energy figure was determined by a division of the degree day calculation for that particular period and actural energy consumption in terms of British Thermal Units. Furnace efficiency was substracted from the total energy input. The furnace efficiency was established at 75% for each season.

Here again energy figures were determined for each season, on the basis of eight pay periods. As each table is compared, general differences may be noted in the consumption of energy.

Figure 8 graphically relates one season to the other. Without

TABLE 6

ENERGY CALCULATIONS FOR SEASON ONE

From	Through	Degree Day Of-Day	Furnace Input CCF	75% Furnace Input	Energy Used BTU x 10^{-6}	Energy Used x 10^{-3} Degree Day
8-25-75	9-23-76	197.8	11	8.25	.825	4.17
9-24-75	10-22-75	305	22	16.5	1.65	5.41
10-23-75	11-20-75	742	73	54.75	5.475	7.379
11-21-75	12-25-75	1830	209	156.75	15.675	8.57
12-26-75	1-25-76	1739	198	148.5	14.85	8.54
1-26-76	2-23-76	1339	153	114.75	11.475	8.57
2-24-76	3-24-76	1370	151	113.25	11.325	8.27
3-25-76	4-25-76	646	54	40.5	4.05	6.27

TABLE 7

ENERGY CALCULATIONS FOR SEASON TWO

From	Through	Degree Day Of-Day	Furnace Input CCF	75% Furnace Input	Energy Used BTU x 10^{-6}	Energy Used BTU x 10^{-3} Degree Day
8-24-76	9-22-76	135	19	14.25	1.425	10.56
9-23-76	10-21-76	554	48	36	3.6	6.5
10-22-76	11-21-76	1065.3	120	90	9.0	8.46
11-22-76	12-26-76	1937.9	223	167.25	16.725	8.63
12-27-76	1-25-77	2044.9	214	160.5	16.05	7.85
1-26-77	2-23-77	1469.6	163	122.25	12.225	8.32
2-24-77	3-24-77	1097.2	103	71.25	7.725	7.04
3.25-77	4-25-77	609	70	5.25	5.25	8.62

TABLE 8

ENERGY CALCULATIONS FOR SEASON THREE

From	Through	Degree Day Of-Day	Furnace Input CCF	*.9 (75% of Furnace Input	Energy Used BTU x 10^{-6}	Energy Used BTU x 10^{-3} Degree Day
8-26-77	9-26-77	197	-6	-12.36	-1.24	-6.29
9-27-77	10-26-77	523	18	12.15	1.215	2.33
10-27-77	11-27-77	1131	69	46.58	4.658	4.12
11-28-77	12-28-77	1795	194	130.95	13.095	7.3
12-29-77	1-29-78	2148.97	232	156.6	15.66	7.29
1-30-78	2-27-78	1790	162	109.35	10.935	6.12
2-28-78	3-29-78	1309	90	60.75	6.075	4.64
3-30-78	4-28-78	693	38	25.65	2.565	3.70

*A correction figure of .9 has been established on heat transfer during season three, to qualify post-test data to pre-test data.

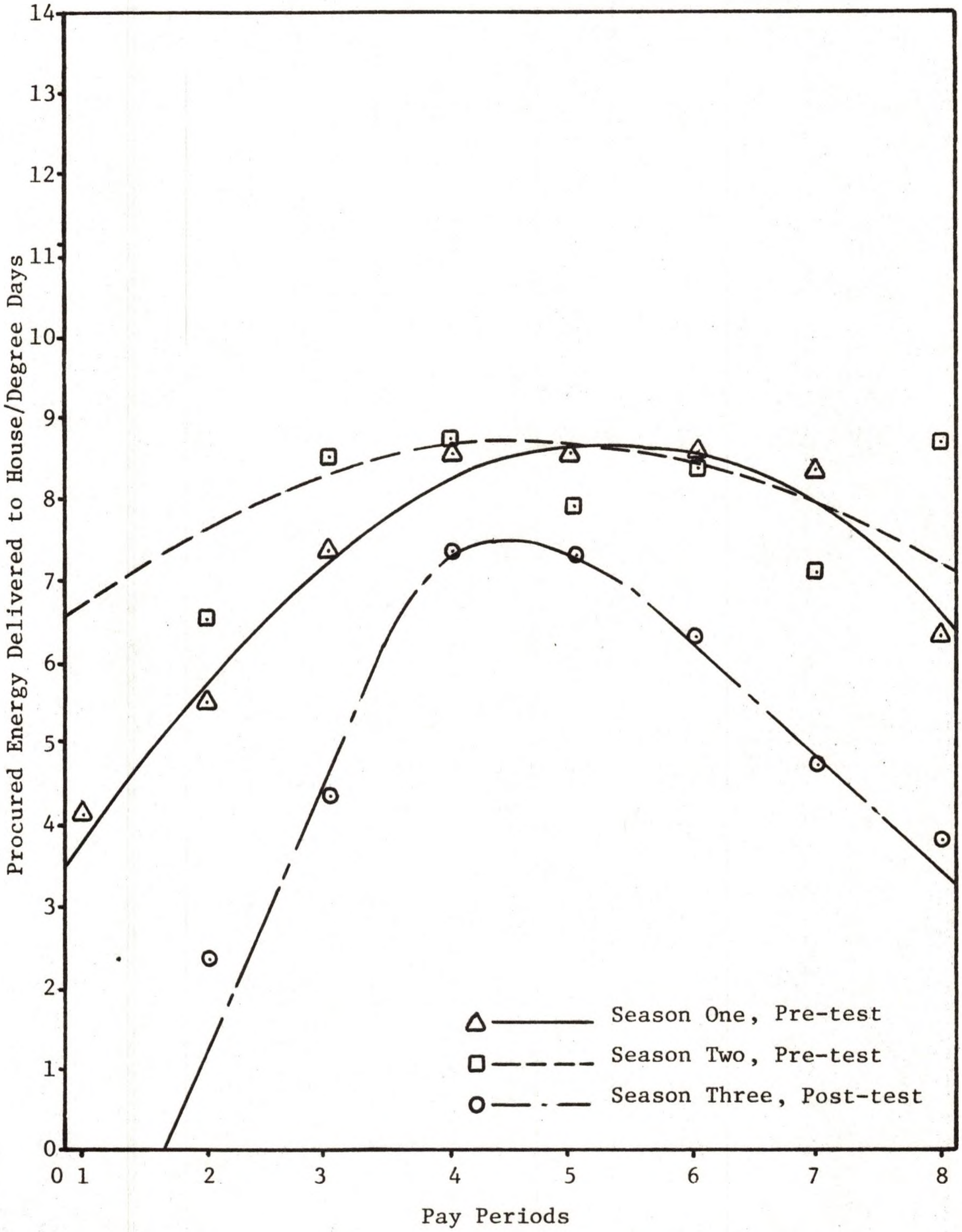


Fig. 8. Energy consumption per seasonal year.

the effects of domestic water, the results of solar energy are easily defined.

When season one and two were compared little difference was observed. Only during the fall months does a distinct separation exist between season one and season two.

In season three a definite difference exists when compared to the other two seasons. In the fall, a large reduction in energy usage observed. As the year progresses, energy usage begins to climb until there is little difference between each session in actual energy consumption.

It is interesting to note, that season one and two tend to level off during the winter months with a gradual rise in the fall and a gradual decline in the spring. Season three offers a contrast to this trend. At one point during December and January, the consumption of energy was nearly as great as the previous two seasons. But the energy level rise in the fall is not as fast and the decline in energy usage begins sooner in the spring. This graph depicts season three to almost peak, while season one and two tend to level off during winter months.

Figure 9 offers further explanation concerning pre-test and post-test relationships. During the cold months when the highest amount of energy is consumed, little difference is seen between any of the three seasons.

Again, as it was presented in Figure 8 season three begins its decline much sooner than either season one or two, with more of a gradual slope. This demonstrates the use of solar energy allowing for a quicker reduction in gas consumption.

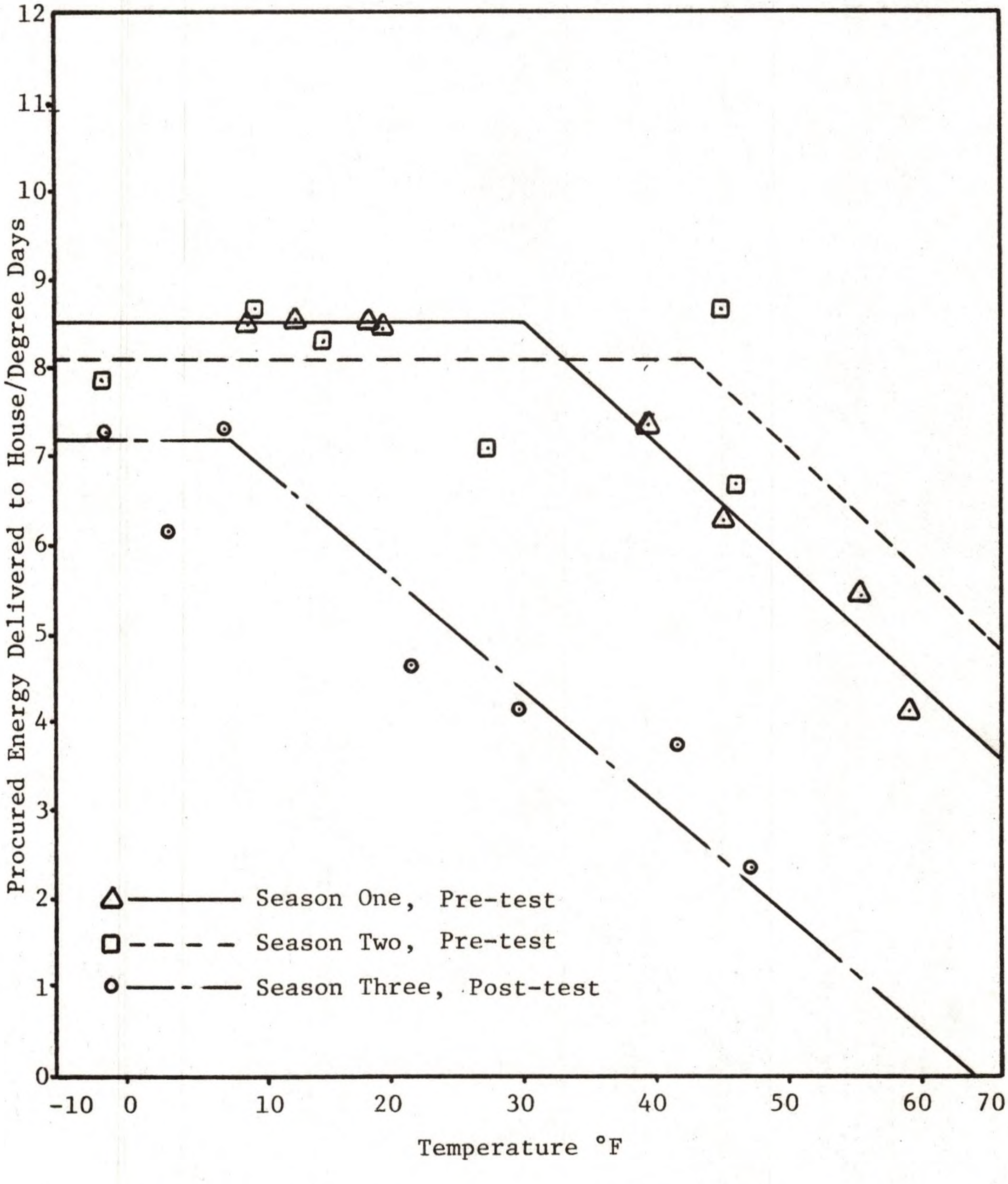


Fig. 9. Seasonal energy consumption relationships.

The Least Squares Test

A least squares test was conducted involving two sets of data: (a) the calculated energy values for season one and season two, and (b) the calculated energy values for season one and season three. In both cases season one becomes the independent variable and seasons two and three the dependent variable.

The data presented in Tables 9 and 10 was used for analysis. The first two columns are energy calculations taken from Tables 6 through 8. The third column becomes the predicted value or criterion. The formula that explains this reaction is $\hat{Y} = A+BX$. $\hat{Y}$ is the predicted value and X is the predictor. A and B are values calculated by the computer.

The author has chosen to reject data from the first pay period of each season. The high temperatures and small degree day figures yielded a figure inconsistent with the rest of the data.

In Table 9, energy calculations were taken from Tables 6 and 8. Season one was the independent variable and season two was the dependable variable.

In Table 10 energy figures were used according to the data in Tables 7 and 8. Season one remains the independent variable and season three is the dependent variable.

Figure 10 combines the data from Tables 9 and 10. Three lines were drawn to illustrate the data. Season one is a 45 degree line representing season one against itself. In seasons two and three, the calculated data was plotted with season one.

The distance that lies between season one and season two is

TABLE 9

LEAST SQUARES TEST DATA, SEASONS ONE AND TWO

Season One BTU/DD, Predictor	Season Two BTU/DD, Dependent Variable	Least Squares Straight Line. Fit-in Season Two Data On Season One. Criterion
5.41	6.50	7.37
7.38	8.46	7.87
8.57	8.63	8.17
8.54	7.85	8.17
8.57	8.32	8.17
8.27	7.04	8.09
6.27	8.62	7.59

TABLE 10

LEAST SQUARES TEST DATA, SEASONS ONE AND THREE

Season One BTU/DD, Predictor	Season Three BTU/DD, Dependent Variable	Least Square Straight Line. Fit-in Season Three Data On Season One. Criterion
5.41	2.33	2.21
7.38	4.12	4.82
8.57	7.30	6.39
8.54	7.29	6.35
8.57	6.12	6.39
8.27	4.64	5.99
6.27	3.70	3.34

difficult to explain. It was only during the cold months that the two lines come together. When this figure was compared to Table 11 an ex-

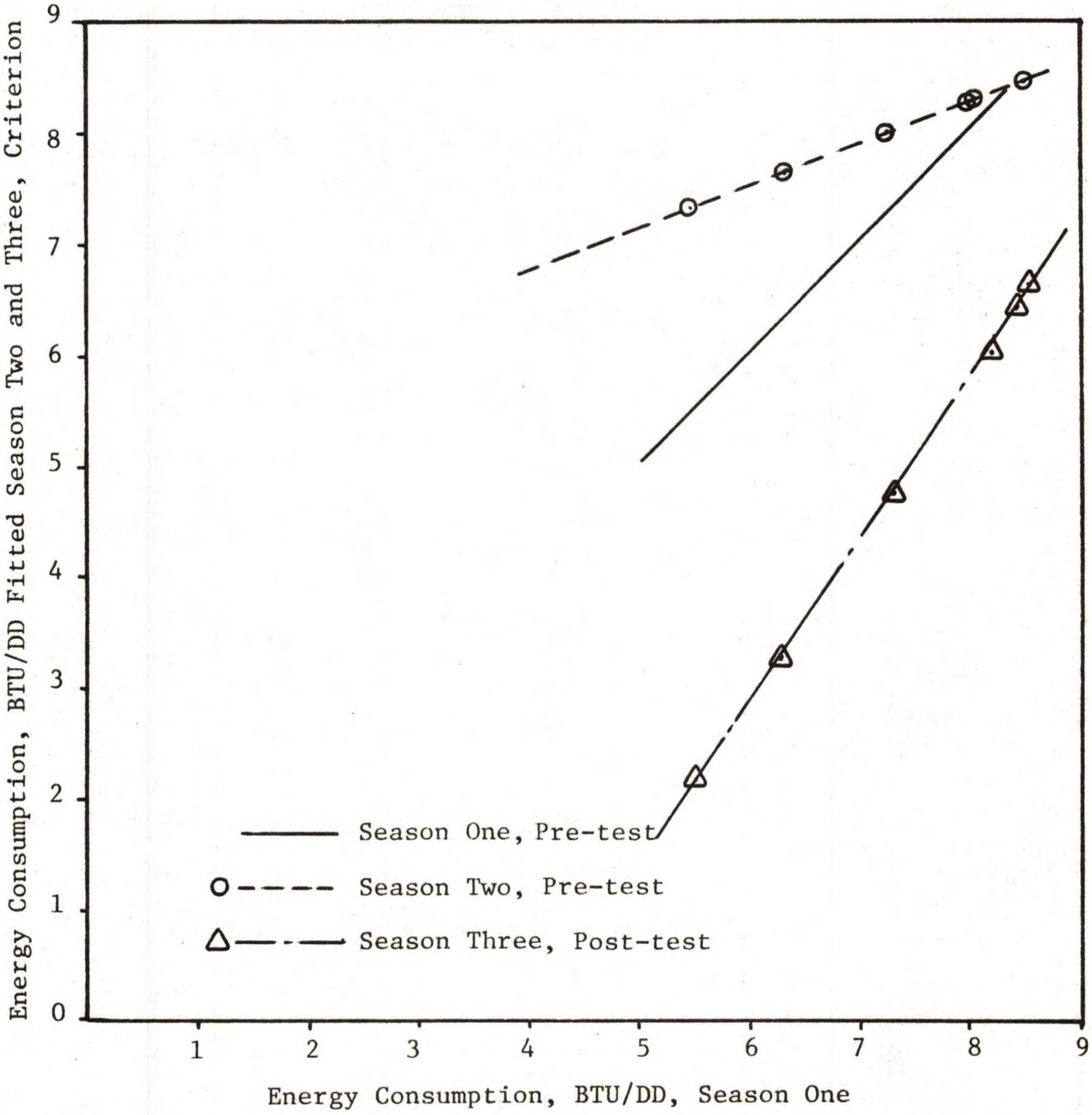


Fig. 10. cross plotting pre-test and post-test specific energy consumption, BTU/DD.

planation may be given.

The seasonal totals presented in this table state a close relationship between season one and season two with a large percentage of difference in season three. It may be concluded that a monthly analysis, as depicted in Figure 10 offers a different explanation than the yearly comparison in Table 11. There appears to be other data that the author has not considered effecting the monthly analysis. Although, the differences presented in Figure 10 and the support of other figurative descriptions would reject the general hypothesis.

TABLE 11

SEASONAL TOTALS

	Season One	Season Two	Season Three	Percentage of Savings Post-test Vs. Pre-test
Energy Used BTU X 10^{-6}	53.01	55.43	35.50	34%

Seasonal Calculations

Energy calculations in terms of the degree day was computed on a seasonal basis. This information may be found in Table 12. A difference was noted between each of the seasonal years. The difference was smaller between season one and season two. In season three a greater difference was observed. It is possible to make two comparisons relating season three to both season one and two: (a) season three demonstrates 28% less gas consumption than season one, and (b)

TABLE 12

SEASONAL CALCULATIONS

From	Through	Degree Day Of-Day	Furnace Input CCF	75% of Furnace Input	Energy Used BTU x 10^{-6}	Energy Used BTU x 10^{-3} / Degree Day
8-25-75	4-25-76	8203	851	638.25	63.83	7.78
8-24-76	4-25-77	8765.2	824	618	61.8	7.05
8-26-77	4-28-78	9599	798	538.65	53.87	5.6

*For season three only, a correction figure of .9 has been established based on heat transfer during the season, to qualify post-test data to pre-test data.

season three demonstrates 21.6% less gas consumption than season two.

If season two is compared to season one, only a 9.4% of difference was observed. The difference between season one and season three is substantially greater.

An Analysis and Economic Evaluation

In this section the author was concerned with the valadity of the data under analysis and how the solar system used in this study relates to present day prices. The evaluation was done by converting the conditions surrounding post-test data to the conditions of pre-test data. The basis of this conversion was on heat transfer. The house heat load rates are 60,747* BTU/hour and 95,289* BTU/hour for pre and post-test conditions respectively.

The formula Emax = AηNPI was used to determine the approximate amount of energy that the solar would produce. This equation was computed as it relates to the system in this study:

Emax = AηNPI

Emax = (320) (.50) (240) (.50) (1300)

Emax = 25×10^6 BTU

A = area of collectors	(320)
η = efficiency of collectors	(50%)
N = number of days	(8x30 = 240)
P = percentage of sun	(50%)
I = solar insolation	(1300 BTU/Day Ft^2)
Emax = sun's energy	25×10^6 BTU

---

*Reference Linfoot

The approximate amount of energy that the air-type solar heating would possibly produce is 25 x 10^6 BTU's. This is based on expected conditions. This value is similar to the value in Appendix C.

To complete this evaluation, it was necessary to determine energy used by the conventional/solar system. The formula that was used to determine this energy value is as follows:

$E_h = (E_p - E_w)_f$

E_h = energy used to keep the house warm.

$_f$ = furnace efficiency

E_w = energy to heat hot water

E_p = energy procured from the powér company

These calculations have all been done and necesary data may be found in Tables 5 and 12. The author has selected season one and season three for comparison basis and omitted season two.

The maximum savings generated by the old and new load (contains an adjusted heat transfer figure of 1.57 as explained in Appendix B) are as follows:

1. The old load (heating only E_h) 25/6312 = 39.6%.
2. The old load (procured energy E_p) = 25/84.3 = 29.7%.
3. The new load (heating only E_h) = 25/63.2 x 1.57 = 25.5%.
4. The new load (procured energy E_p) = 25/84.3 x 1.57 = 18.8%.

At this point, a table may be set up that compares each season. What this table suggests is that the figures under analysis, based on the present heat transfer figure, are high. This is demonstrated that 52% as compared to previous computed for maximum savings of 25.5%.

The economics include the 1134 CCF of gas consumption and a

TABLE 13

CORRECTED HEAT LOAD

Energy (CCF)	Degree Day	Collectors	Energy Used BTU Degree Day	Raw Percentage	Heat Load Correction	Savings
843	8203	No	7.7		7.7	
1134	9579	Yes	6.25	18.8%	3.98	52%

quoted price of 32.5 cents per CCF from Northern States Power Company. This yields a cost of $368.55. The 18.8% increases this cost to $437.84, with a savings of $69.29. This total may be increased a light amount upon consideration of additional room area. When this figure was applied the initial installation cost of $9,500* with an interest of percentage of 10%, the total seasonal savings would not cover the $950 interest charge. At the present, this is a negative aspect for the individual homeowner, but if each individual throughout this nation could save 18.8% in energy consumption this would have a large impact toward greater energy conservation. The homeowner must also consider rising energy costs, depletion of fossil fuels, and reduction in cost of solar energy equipment in the near future. Each of these considerations will play a role in the acceptance of this energy alternative.

*Reference Linfoot

CHAPTER V

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

Summary

Solar energy has become an important consideration in the area of energy research. Due to the depletion of fossil fuels, energy researchers must develop alternatives that will curb energy shortages.

The nature of this study was to determine the impact of supplementary active air-type solar heat on the conventional heating system of a residential home. Data was collected from a specific conventional/solar heating system, on a residential home owned by Mr. Linfoot.

The hypothesis under investigation was stated as follows: There will be no significant difference between the pre-test and post-test mean gas consumption resulting from air-type solar heating units as treatment.

The findings demonstrated that by the least square analysis a sufficient difference to reject the general hypothesis. Figure 10 demonstrated that pre-test data was consistently higher in gas consumption. Although, these differences are not totally clear, there is sufficient data to reject the general hypothesis.

The study revealed that with domestic water the solar effects were not clearly defined. It was necessary to subtract this amount of energy for each season.

The primary effects of solar energy were as follows: (a) a small decrease in the consumption of gas during the coldest months, and (b) a quicker decrease in gas consumption with warmer weather conditions. According to the acquired data, the solar system produced a 25.5% savings in the consumption of gas during a season. Economically, this is not a strong figure when considering the initial cost of installation.

Although there is limited data to reject the general hypothesis, much research has suggested an ever increasing need for more research in solar energy. This research stems from previously cited sources that conclude the need for alternative forms of energy because of depletion of fossil fuels.

This study was concerned with: (a) reviewing literature regarding the structural design of active air-type solar heating units, (b) collecting data from a home utilizing air-type solar heating and conventional system, (c) analyzing the data and determining the impact of air-type solar heating units on conventional heating systems, and (d) determining the combined effect of an air-type solar heating unit conventional heating system in terms of economical implications.

Conclusions

Supplementary solar heating may upgrade the energy efficiency of a home. Solar installation may also enhance the architectural design of a new home or become part of an existing house by retrofit. These modifications may include such additions as: (a) insulation, (b) windows and (c) roof area or a structure that would support solar collectors.

The relationship that existed between pre-test data demonstrated little difference. The actual gas consumption varied little from season one to season two. The energy value, which includes temperature, was only .73 higher in season one as compared to season two. This demonstrates less than 10% difference.

Post-test data demonstrated a difference from pre-test data. The combined effect of pre-test analysis yielded a 25.5% greater consumption of gas than in post-test analysis.

On a monthly basis, the solar impact was higher during the warmer months and greater savings were recorded. As the year progressed to the coldest months of the season, the impact of solar heating decreased greatly. This was a result of several reasons: (a) the extreme impact of the cold upon the solar collectors and home, (b) the low angle of the sun, and (c) the actual collection time, while the sun is in the sky.

It has also been concluded from this study that the economics of solar heating has no pay back period. Although, conditions of a pay back period depends on what the owner has invested.

In the final analysis, the author conducted a check on the data that was used in this study. This has demonstrated a lack of sufficient data for a thorough analysis of the supplementary solar system. Although, conclusions that have been offered by this study do align themselves with other research in the field.

Recommendations

1. It is the author's recommendation that a study be done on varied thermostat settings. This may be analyzed on a weekly basis during

warmer months and continue into the colder months of the year.

2. An investigation into the development of solar economics by incorporating other solar energy techniques to help reduce the pay back period is also recommended. An example of such an investigation would be numerous forms of passive solar methods.

3. A recommendation in which the author sees a great need for investigation lies in the area of education of solar energy. It is important that education keep in touch with research. This investigation may take one of two approaches: (a) a survey could be prepared to gather data concerning industrial educators reaction to instruction of solar energy in their classes, and (b) to develop a course of study in solar energy.

APPENDIX A

COLLECTION INSTRUMENT

TEMPERATURE VALUES

GAS CONSUMPTION VALUES

APPENDIX B

HEAT TRANSFER CORRECTION

The actual data relating to heat transfer that was gathered from Mr. Linfoot is as follows:

1. Pre-test heat transfer was 60,747 BTU/hour

2. Post-test heat transfer is 95,289 BTU/hour

To arrive at the figure that would adjust the conditions surrounding post-test data to the conditions of pre-test data it may be calculated in the following procedure:

$$\frac{\text{POST-TEST DATA}}{\text{PRE-TEST DATA}} = \frac{95,289}{60,747} = 1.57 \text{ correction}$$

This provides the correction necessary to establish a comparison in heating efficiency from pre-test data to post-test data.

APPENDIX C

FLAT PLAE COLLECTOR HEAT GAIN DATA

WORKSHEET A. 1

FLAT PLATE COLLECTOR HEAT GAIN PER FT²

SOLAR RESEARCH INC.

ORIENTATION
CITY Grand Forks
LATITUDE 45° (48°)
TILT 60 (58)
CHOSEN BY DESIGNER

COLLECTOR		
DESIGN MEAN TEMP. °F *CHOSEN BY DESIGNER*	MAXIMUM EFFICIENCY % *MANUFACTURER'S CURVE*	EFFICIENCY LOSS RATE %/(°F/(BTUH/FT²)) *MANUFACTURER'S CURVE*
105°c ~~95~~	62	88
a	b	c

IDENTIFICATION
NAME Lin Foot
DATE 9-12-77
PREPARED BY Bil

CLEARNESS # *EXHIBIT A.1*	1.05
	d

COLUMN	AMB. TEMP. *EXHIBIT A.2*	COLLECTOR TEMP. MINUS AMB. TEMP. *a-B*	CLEAR DAY HOURLY INSOL. *EXHIBITS A.3-A.8* A.6	INSOLATION RATIO *C÷D*	COLLECTOR EFFICIENCY LOSS *c×E*	COLLECTOR EFFICIENCY *(b-F)/100*	CLEAR DAY DAILY INSOL. *6×D*	CLEAR DAY SOLAR GAIN *G×H*	PERCENTAGE OF SUNSHINE *(EXHIBIT A.9)/100*	DAILY SOLAR GAIN PER FT² *I×J×d*	DAYS PER MONTH	MONTHLY SOLAR GAIN PER FT² *K×L/1000*
MONTH	°F	F	BTUH/FT²	°F/BTUH FT²	%	DECIMAL	(BTU/FT²) DAY	(BTU/FT²) DAY	DECIMAL	(BTU/FT²) DAY		(KBTU/FT²) MO
A	B	C	D	E	F	G	H	I	J	K	L	M
JAN.	5.3	99.7	216	.462	40.6	.214	1296	277	.53	154	31	4.774
FEB.	12.6	92.4	255	.363	31.9	.301	1530	461	.60	290	28	8.132
MAR.	25.2	79.8	261	.306	26.9	.351	1566	550	.59	341	31	10.562
APR.	43.4	61.6	245	.251	22.1	.399	1470	587	.60	370	30	11.094
MAY	57.8	47.2	229	.206	18.1	.439	1374	603	.59	374	31	11.6
JUN.	67.7	37.3	220	.170	14.9	.471	1320	622	.62	405	30	12.1
JULY	72.8	32.2	224	.144	12.7	.493	1344	663	.71	494	31	15.3
AUG.	71.6	33.4	237	.141	12.4	.496	1422	705	.67	511	31	15.8
SEPT.	59.9	45.1	248	.182	16.0	.460	1488	684	.59	424	30	12.7
OCT.	48.8	56.2	242	.232	20.4	.416	1452	604	.56	355	31	11.0
NOV.	29.4	75.6	212	.357	31.4	.306	1272	389	.44	180	30	5.4
DEC.	14.0	91.0	192	.474	41.7	.203	1152	234	.45	110	31	3.4

Source: Mr. Linfoot, Grand Forks, North Dakota

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