TX-SES TECHNICAL BULLETIN

VOLUME 1 NO 4 1977

USE OF MICRO ELECTRONICS IN SOLAR CONTROL SYSTEMS

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ABSTRACT

Various micro-electronic techiques with regard to solar control systems are compared, ranging from simple implemented logic to the far extreme; the installation and use of microprocessors in sophisticated control systems. Logical inputs from the system provide the basis for electronic decisions for simple on/off controls, those due to weather conditions, storage capacity, and further to the varying cost of commercial power during prime times (determining the most judicious use of store solar energy). Extensive use of integrated circuit technology in both analog and digital realms allows the design engineer with limited electronic expertise to implement logically oriented simple controls for inexpensive energy systems. Highly qualified personnel may use microprocessor capability to control virtually any and all functions of larger or commercial systems in the most energy efficient manner feasible.

INTRODUCTION...............................There are today virtually a myriad of solar systems on the market and available to the consumer, ranging from the simplest of hot water heaters for potable and domestic hot water to large scale hot water and hot air applications for space heating. On the other side of the periphery, systems for industrial process heat and large scale electrical conversions are begining to appear. In each of these systems to a measure are incorporated, and to a larger degree are needed, sophisticated control systems which may utilize the full energy output of the system. Any alternative system has in mind as its priority prerequisite the conservation of energy, therefore it is not only proper but a necessity that the control system be not only efficient but frugal as well in its own use of energy. Many controllers seem up to this point to have relied on common industrial equipment, generally electromechanical, and in the far extreme have become such power consumptive devices as to require more energy for control than that which a minimal system may produce for hot water. In this regard the purpose of this dissertation then is to stimulate some creative thought relating to the implementation and use of an entire generation of solid state devices now available to us, ranging from the simplest of diodes and transistors to various types of gated logic, and at the far end of the spectrum the newest controller of all, the microprocessor.

HOT WATER SYSTEMS

The most prolific systems at this time of course are hot water heaters. Further it seems that little thought has been given to sophisticated but conservative control systems for these ddevices, most of them being turned on and off by some series of relays, thermostats, etc., generally relying upon a timed cycle. If a small amount of thouht is given to a logic design of fairly simple construction we may drastically improve the working efficiency of the system. The first logical step in any such system therefore is the monitoring of its status. Being thermal systems, this can easily be done via the very common operational amplifier, connected in a variety of fashions to a group of input devices, which in this case we will assume to be thermistors. Thermistors are resistive devices which vary quite linearly in proportion to temperature, are available in a considerable number of mechanical configurations, and require very little power to operate. Depending upon configuration, the operational amplifier may be hooked up as a simple amplifier, a differential amplifier perhaps sensing the difference in input and output temperature from the collector or the differential between output temperatures from the collectors and the average temperature within the storage system,or it may be utilized in a summing or integrating fashion.

Optical approaches, relying upn the visibility of the sun for input, are able to take little into account with regard to the status of the system itself. Either of these approaches, however, is considerably more accurate than a simple timer such as is found in many systems of this genre. Op-amps are available in package configurations of 1,2,and 4 units per single integrated circut package and therefore lend themselves easily to a minimum component count. Once the number,type and distribution of sensors have been determined, and the mathematical relationship between them has been established, rather conventional electronics may be driven by the op-amps directly to manipulate whatever physical equipment is involved to cause the desired action. This equipment may be kept entirely solid state, requiring minimal current draw; however, op-amps do require the general usage of a split power supply, complicating the design slightly.

A LOGICAL DESIGN

As we expand our electronic logic capabilities to the use of various common gate type circuits, we may increase our capability not only to the point of controlling a simple hot water heater but perhaps the entire space heating system of a residence as is indicated in Figure 1. In this case we have a rather large array of collection devices, which do not represent a total energy system for the house in question; therefore, the array may be considered either primary or back-up to the existing heating and/or cooling system of the house in question. Now we begin to look at the real possibilities of what may be termed implemented logic, or a small, dedicated, low cost computer responsible for the control of the entire system. Initially we may concern ourselves with only four areas, those being 1)the solar or other alternative energy input, 2)the storage or longevity condition of that system, 3) the status of environmental conditions within the residence, and 4)the considered usage of standard heating/cooling appliances. Again we begin by asking our collector system if indeed there is sufficient solar energy to be worthwhile collecting, and presumably upon receiving an affirmative response direct that energy to the proper location, that is to say storage, if it is not to be used immediately, or to a working application such as domestic hot water for immediate use. Next we come to a point of considering that our collection system is quite efficient and at some point our storage or containment facilities may approach or meet a "full" energy condition, at which point we would want to instruct the collection system to cease its operation,knowing that there was no more room for thermal input. This is dictated if the storage system contains the same heat grade as is output by the collection system. No more may be entered into the system, according to basic laws of thermodynamics, for we must have a level of 'N+1'to gain entrance into the storage system at level 'N'. Here again the logic of the control system can say to the collection devices that they are to remain in a passive state until their working fluid attains sufficient temperature to overcome the energy boundry of the storage system, at which point that amount of heat will be released into storage and the operation again ceased until a further increase could be achieved. This type of device is a simple decision making component which simply analyzes two sectors, A&B,determining which is greater and governing its action by the result. Thus far nothing complicated has arisen in the system at all and yet it has an actual "intelligence" of a sort of its own by which the system will be operated. Now the system reaches another point in its decision making ability,that being the status of demand imposed upon input and storage via the household in question. Again we turn to very simple logic querying the system as to whether space heating is needed to bring the environment inside the home to a desired temperature, asking whether this should be a heating or a cooling process (in a situation where the solar input is provided to a heat pump this application fits ideally if not perfectly) and giving the logic components the authority to take action based upon the results of their very simple logical answers.

The sensors providing inputs to this logic array may be the same thermistors previously discussed, simply set to turn on a transistor for the appropriate logic input, or any other type of thermal switch which we might envision. The questons answered by these inputs may be dealt with by means of one or two integrated circuit packages containing various sorts of "OR" gates. OR gates basically have the logic function that says if one or more of these conditions is true, then the output of the gate is true, or if the logic system is arranged in a negative fashion the converse takes place. Additionally, an "exclusive OR" function is available. Thus by structuring this simple combination of functions within a few components we may provide control instruction to virtually all of our alternative energy system (which at some time we hope to be the prime energy system, relegating what is now known as the standard system to an alternative system).

Logically the next function of our control system will be to bring into its domain the existing heating/cooling equipment.Again the query must be made: is there sufficient energy contained within the storage system to meet the needs of our hypothetical residence or must we rely on conventional means? This decision again is very simple and will produce a simple yes or no response at which point the chosen system will be activated. Here we may branch into another logic function known as the "AND" function. This basically says that for a given number of inputs, which may range from two to in excess of six or eight, if the logic system finds A&B&C&D, etc., to be true it will provide a true output which may be used directly or inverted to provide the proper command to the alternative or conventional system. That is to say, in a worst case condition that the solar input at the moment is insufficient for the operation AND the storage system is depleted, AND the environment of the house dictates some change in temperature or such other function as it may have capability, THEN the conventional system will be placed into operation.The converse and some deviation from this system may be arranged such that if the immediate solar input is adequate OR is not adequate AND the storage system has sufficient reserves AND the environmental qualifications of the residence dictate action then the alternative or solar system will be brought into play. The compactness simplicity, and economy, both in hardware and energy expenditure terms of this type control system are still a great deal more efficient that what would be known as a conventional control system. With the exception of sensors which will be common to any system, whether it be alternative or conventional, ranging from thermostats to preiously mentioned components, the logic array may amount to a very small power supply capable of suppling perhaps as much as 400 to 500 milliamps maximum at 5 volts, and 4 to 5 integrated circuits of various types ranging in price from less than a dime to no more than $1. We have created a very efficient, economical control system which is actually quite capable of making a fairly wide range of decisions in the energy processes of our home. Herein becomes apparent the true value of what we have termed "implemented logic", that is to say we are not interested in this application in "number crunching" devices which make manifold calculations, but rather simple comparators which will as the name implies compare the status of various parts of a system and make a logical decision based thereupon. There will of course be neccessary some power components to actuate the real-world machinery in the house,but again being solid state, the cost advantage of the microelectronics approach is more than significant enough to justify its design, and its expense is surely frugal enough to justify its existance.

One additional note is that as we reach a point where electromechanical controls must be used, such as solenoids, relays, etc., that they be of the latching type, therefore requiring power only during the transition, rather than an active "on" or "off" state.

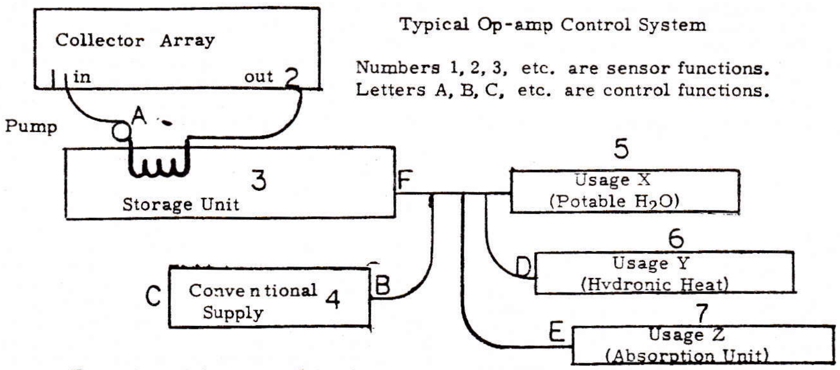
THE MICROPROCESSOR..........................The field of micro electronics has now only been skimmed, with the most exciting powerful tool yet to be discussed. There are available today a variety of microprocessors, virtually entire computer systems on a single chip which have the potential to become the most sophisticated, reliable, advanced control mechanism for large energy systems available to date. Microprocessors are relatively cheap in hardware costs, dedicated units for the purpose of controllers are currently available beginning at a range of about $150. Power consumption is minimal, ranging to an order of no more than 2 to 3 amps at 5 volts for the entire system, about the power consumed by a 15 watt light bulb. For purposes of our application, it should in size, with speed and versatility of application becoming the most predominate factors. Hardware for a microprocessor control system will look somewhat similar to that found in an implemented logic unit, however most of the discrete logic functions found in the gates described in the previous section may be handled in software. That is to say that if an OR function is to be exercised upon some set of inputs, it may merely become a definable category within the memory of the processor. Further sophistication in reality makes the processor even simpler, as it may be provided in its resident memory the parameters about which all of its control functions are to be exercised. This memory can from time to time be up dated as criteria change, but basically becomes a table in which the processor will look up data,compare it with the existing inputs, and take the appropriate output action.

Most microprocessors have the capability of addressing 65,000 words of memory, however for an extremely sophisticated system perhaps as much as 8 to 12k are all that would be necessary. Judicious design will see to it that even less may be required, however "memory" is cheap enough at this time that it may be used rather flagrantly to simplify design criteria. Such a system may quite easily be constructed on a printed circuit board area no bigger than 6 by 6 inches.

With such sophistication, the decision making ability of the control system takes on an entirely new form such that monitoring and control in more areas of the living environment are possible. No longer is it necessary to consider only an alternative system. The active system may be controlled taking into account the status of any passive operations involved in the structure. Items which preiously were simply too much clutter to deal with, attic fans, systematic ventilation and shading, and conservation of other valuable resources, such as water,now become rather routine matters for the processor.

Actual "intelligent" decisions become a reality for the energy system, as the processor may take into account pricing advantages offered by public utilities for consumpption rates in "nonprime time" portions of the day. Reports have been submitted from some areas of the country that between the hours of 6 and 11 PM,energy costs may be double or triple that during other times of the day. With such data present, the microprocessor can analyze the days's input, the status of the storage system, the local ambient conditions, and spend the energy of the alternative system during the most judicious time possible. Total environmental control within structres ranging in magnitude from small residences to large apartment complexes are realistically possibele through utilization of the microprocessor. Its ability to operate at megahertz speeds, look up and act upon instructions found in memory in small numbers of nano-seconds allow the machine to have the appearance of being in control of all of its various functions at the same time.

Microprocssor design will for the time being be largely a function of the design engineer, however as integrated circiut technology becomes easier to deal with, discrete components become fewer in number, we have every right to expect that we may see many more such systems available in the near future. As regards circuit packaging, it should be noted that there are available today most types of discrete components, i.e., resistors, capacitors, diodes,etc.,available in the familiar dual-in-line package or chip, which quite realistically become "plug in replaceable" or programmable elements to interact with such a system. The day is here when an individual may look at a small board populated only by chips, with perhaps several ribbon cables leading out of it to the various portions of his house, knowing that the device will control his entire internal environment when he is at work or play, away on vacation, and maintain it in whatever status he decides his environment should be.



Examples of Operational Logic.

- if 2 > 1 (hotter), turn on A
- if 2 > 3, turn on A
- if 3 = proper temperature, turn off C
- if 5, 6, 7 < desired temperature, turn on B &C, turn off F
- if 3 > desired temperature, turn off A, B, & C
- if 2 < 3, but 3 > desired temperature, turn off A, B, & C
- if 6 or 7 indicate demand for heating or cooling, turn on D, or, E as required

Not including sensors, Controller must be capable of making no more than 7 comparisons, only two being any more than two ended differential measurements.

FIG. 1

CONCLUSION

In the text of so short a paper we naturally cannot provide a course in solid state electronics from which the engineer or owner may simply dash out and construct such a system.It is however felt that should the purposes of this presentation be realized we will begin to see a large committment toward new generation solid state devices in the energy science of the future, and we owe it to ourselve, our consumers, and our species to avail ourselves of the most efficient means of control and at the least significant cost possible.

SOLAR HEATING WITH ICE

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ABSTRACT

This concept, which involves storing solar energy in the heat of fusion of ice, and extracting the energy by heat pump, has several significant advantages over hot water storage. These include projected higher heat pump efficiencies than could be expected for an air to air heat pump; a storage volume of about a sixth of that required for hot water storage; a third of the area of solar panels that would be required for hot water, because the efficciency will be about three times as great with inlet water near the ice point; and existing dwellings may be retrofitted without major renovation because the storage unit could be external to the house. Some disadvantages are:significant external power is used; standard heat pumps operate poorly near the ice point and so special designs must be developed; the mechanical problems of dumping ice to use water from the mains as a back-up are formidable; and significant engineering design and evaluation work must be done before experimentation can be considered.

BACKGROUND OF THE PROBLEM

Present heating methods use enormous amounts of fossil fuels, and these methods will continue to be used unless more efficient ways are found,since it would be wasteful to destroy existing structures and build all new. We might think of existing structures as "energy-in-place", and then consider alternate heating methods as means of reducing operating expenses and saving fuel. Any system that offers more efficient heating than present methods, could save more energy than will be saved by new construction for years to come simply because of the enormous numbers of existing structures.

Much effort is currently being directed toward utilizing solar energy for residential heating. Most of these systems colect the heat energy of the sun's rays and store it at a temperature higher than that desired in the residence. Such heat storage usually requires a large mass and volume (typically several tons for an average dwellng) and also requires that the storage be insulated from heat losses to the outside air. This insulation heat loss from storage is "lost" to the house to be heated, which is not really lost then.

Placing the large heat storage area inside a house when it is being built is relatively easy, although it may be expensive. Placing such a large heat storage area inside most existing houses is presently beyond the realm of practicality. Placing such storage inside one story houses built on a concrete slab, inside a mobile home, or a travel trailer is even more impractical.

Attempts have been made to reduce the space, mass, and first cost of heat storage. These have included use of denser materials and heat of fusion of certain salts. These schemes also commonly stored the heat at a higher temperature than was to be maintained in the structure.

HEAT STORAGE FOR RESIDENTIAL USE

Water is a popular medium for heat storage in solar heated buildings because of its several desirable characteristics.Most of those applications use only the sensible heat (that which can be detected by sensing a change in temperature), and do not use the heat of vaporization (to steam) or the heat of fusion (to ice). Both of these latter processes typically take place at a constant temperature and are associated with considerable transfer of heat, even though the temperature does not change. The use of steam for heat storage is ruled out for safety reasons, but the expansion is provided for. In changing a pound of water to ice, 144 BTU's must be extracted (at atmosperic pressures).

A typical installation using water as heat storage, might show a change of 40 degrees F. in a 24-hour period (from 140 to 100 degrees F.). This would indicate that 40 BTU's had been stored and then removed for each pound of water. If that same pound of water had been frozen, 252 BTU's could have been stored in less than one-sixth as much water if that water had been taken from 140 degrees F. and frozen at 32 degrees F. Referring again to a typical water storage system that had 1500 gallons (MIT House) of water storage, we could exchange a comparable amount of heat in 250 gallons,if we took the water to ice as described above.

A point in considering heat losses from the storage mass is worth noting here; heat losses are related to the difference in temperature between the storage mass and the outside air, and the effectiveness of insulation. If we are storing heat near the freezing temperature, we need much less insulation than if we were storing heat at 140 degrees F. This means that a low temperature storage could be outside the structure to be heated without causing large storage losses. In fact, if outside air were above freezing, there could be heat transferred into storage from the surroundings.

From the foregoing it is seen that heat storage is a major problem in using solar energy to heat existing buildings, and that the storage volume and insulation would be greatly reduced if we could extract all the heat necessary to freeze the water. A heat pump does just this.

HEAT PUMPS

The easiest description of a heat pump is that it is "an inside-out refrigerator,"since most people are familiar with refrigerators and the fact that refrigerators have coils on the back that give off heat. For our purposes we need only recognize that we can extract heat from a cold body such as water (freezing it to ice) and "pump" that heat up to room temperature to heat a house. The most common model of heat pump for residential use employ Freon refrigerants, operate "air-to-air", are slightly larger than an ordinary refrigerator, and are driven by an electric motor. Heat pump technology is well developed, many models are readily available, and they have been shown to be more energy-efficient than burning fuels in many climates. For example,one manufacturer claims their product is 2 1/2 times as efficient as ordinary resistance heating.New Mexico has many areas where heat pumps, even though they use electricity, are more economical than fossil fuels for heating residences.

SOLAR PANELS FOR COLLECTING HEAT

A wide range of solar panels are now commercially available and more attention is being directed to their use and further development. The wide range of technical literature and proprietary advertising will not be elaborated on here.

It should be noted, however, that efficiency of solar collecting panels is strongly dependent upon output temperature. At high temperatures a typical collector may be only 25% efficient,but near freezing it could be near 80%. This means that roughly one-third of the collector area would be needed to collect storable heat at near freezing temperatures, compared to the higher temperature storage required in other systems.

PROPOSED SYSTEM ASPECTS

Basic Operation. The heat pump, powered by electricity,would take heat out of water and pump that heat into the structure to be heated. When enough heat had been taken out of the water to reach freezing temperature, the operation would continue to remove heat, freezing the water to ice. The water would give up 144 BTU per pound in changing to ice. Typically, there would be enough water, so that the BTU's extracted would be sufficient to provide heat to the structure overnight. The following day, brine circulating through solar panels would pick up heat and carry that heat to coils in the bottom of the water tank to melt the ice and warm the water. When heat was needed in the structure, the cycle would be repeated.

The basic components of the heating system would be the heat pump, water tank and solar panels.

Heat Pump. A heat pump could be chosen from commercially available units on the basis of heat capacity, operating temperatures, coil characteristics (water-to-air preferably), size, cost, and coefficient-of-performance. Sufficient differences exist between various products, so that there should be several "off-the-shelf"items that would meet the desired specifications. Commercial "ice-makers" used in restaurants might be more suitable than air to air heat pumps.

Water Tank. The size of the water tank would be determined by the desired storage capacity, solar panel capacity, and operating temperatures. There could be three operating conditions.

1.Using specific heat of water, from the highest temperature the solar panels can provide down to the lowest temperature, freezing, (1 BTU per pound).

2.Using heat of fusion of water at freezing temperature (144 BTU per pound).

3.Using heat of fusion of water, but dumping the ice. This could be an emergency measure in the case of extreme cold, lack of sunlight, or inadequate capacity when enough solar energy cannot be stored through the day to melt the ice. This could be considered a "back-up" system for (1) and (2). (Many other solar heating systems require a fossil fuel back-up system to carry through extended inclement weather.)

The water tank would not require much insulation, but should be a design that does not burst upon freezing. Under some light duty conditions (described below) insulation might be a disadvantage.

Solar Panels. Several companies have recently been offering more varieties of solar panels, so there is a fairly good selection of stock items to choose from. Choice would be made on the basis of efficiency, cost, ruggedness, size and weight, flexibility in application, etc. Probably any that use water could use brine. (Brine is not necessarily corrosive; it could be standard automobile anti-freeze). A small pump would propably be needed to circulate the brine. Efficiency would be high since ambient air would often be above freezing in the daytime and solar panels are more efficient at lower temperatures.

Controls and Instruments. The heat pump would most likely include thermostatic controls to regulate heat demand. Controls would be needed for the brine pump if they were not part of the solar panel system. Monitoring and recording equipment might consist of temperature and flow measuring devices and chart recorders.

Ice Removal. One possible source of trouble,which cannot be easily anticipated until some actual experimental runs are made, is ice removal. This is related somewhat to the size of the water tank.

1.If the system is designed for ice to form on the coil, with heat transfer through the ice, and adequate water for all conditions, then no ice would be removed. This would require a storage volume sufficient for the worst conditions and coils of large area becauuse of the poor heat transfer through ice. Coils would also have to be capable of withstanding daily freezing cycles. This would be a maximum size storage version.

2. A smaller sized version would strive for smaller coil size by maintaining the better heat transfer characteristics of water. Ice would have to be removed from the coils either mechanically or naturally by convection and appropriate coil design. This does not appear to be an insurmountable problem; the commercial ice-makers commonly used in restaurants obviously have solved the problem, if one indeed exists. The ideal configuration would have both the heating coils and cooling coils in the bottom of the water tank,with natural convection acting to transfer the ice to the top of the tank during the freezing cycle and then natural convection again acting to cause warm water to rise and melt the ice in the melting cycle. One alternative might be to pump water past the coil under high pressure so that it would be supercooled, and then into the tank where it could freeze after the pressure had been released. This would improve the heat transfer characteristics dramatically and allow smaller coils, but would add the complexity of another pump.

Another feature that might be incorporated, which is alluded to in part (3) of the Water Tank heading above, is that of providing for removal of ice at the top of the water tank and adding make-up water. This might be as simple as allowing the makeup water to float ice over the edge of the tank, or a more positive method might be necessary.

Light Duty Operation. The above concern with worst-case conditions obscures the fact that there are many warm,sunny days with cool nights but not below freezing. It should be pointed out that under such conditions, when the solar panels have warmed the water in the tank to the maximum amount, the heat pump would require little energy because its source of heat is so near the temperature desired in the structure. Indeed, under such condition the water might supply enough heat without having to freeze.

Previous Work.The concept of heating buildings using the heat of fusion of water is not new. The largest effort we are aware of is in progress at the also working on such a system. The A.C.E.S. system (Annual Cycle Energy System) of the Oak Ridge Laboratory is shown in Figure

As the name implies, this system is to complete one cycle per year;freezing 20,000 gallons of water in winter and melting that 20,000 gallons in the summer, thus heating the house in winter and cooling it in summer. We would point out that 20,000 gallons is a lot of water,being 27' x 10' x 10'(feet) in a typical configuration. We might be able to find conditions where the block of ice would be bigger than the building it was heating!

TABLE I

PROPOSED SYSTEM FOR SOLAR HEATING WITH ICE

ADVANTAGES
Higher system efficienty than air to air heat pump
Small storage volume (1/6 normal H2o)
Minimum insulation of storage
Smaller solar panels (1/3 average size)
Backup system uses water from mains
Summer cooling with heat pump
Unit could be external to house
Existing dwellings may be retrofited without major renovation
DISADVANTAGES
Untested design
(a) Heat pump details unknown
(b) Water and ice tank characteristics unknown
Uses external power
SUMMARY
The proposed system may be a more economical heating system for existing dwellings and mobile or portable homes that do not have adequate space for conventional heat storage or have a limited surface area for solar panels. Success will depend largely on the characteristics of the H2o to air heat pump, and it is hoped some interested company will develop such a heat pump and storage tank.

SOLAR HEATING AND COOLING: DWELLING DESIGN CONCEPTS.

AIA Research Corp., *Solar Dwelling Design Concepts* (Supt. of Docs., G.P.O., Washington, DC, 20402, 1976) Stock Number 023-000-00334-1; $2.30

This publication is designed to introduce the field of solar energy and describe how the use of solar heating and cooling is dependent on the design of the dwelling and the local siting of the structure. However, the book covers a large number of the aspects of solar heating and cooling using a component and systems approach. This provides a very good introduction to this topic for the general public.

The book contains chapters on the history of solar heating and cooling, solar heating/cooling and domestic hot water systems, solar dwelling design, site planning, and two chapters, which constitute approximately 55% of the book, on solar dwelling designs. Chapter five considers traditional dwelling designs in which possible solar collection systems have been integrated. Chapter six presents a number of solar dwelling design concepts developed by different architectural firms for the various climatic regions. The book closes with a very short chapter, number seven, on the future. In fact, this chapter was the weakest and most disappointing chapter in the book. Chapters three, on the factors influencing building design, and four, on site planning, were found by the reviewer to be the best chapters in the book for general information on climatic factors which help to determine building energy load demands. The site selection factors list is very well organized, and is one of the best single page summaries available.

Some of the strong points are the extensive use of graphics and the general quality of the writing. The book also has a number of weak points, the major ones are the lack of extensive references and again the drawings used. While they are good for general conceptual development, they lack, especially in the case of the solar collector systems, specific graphic detailing with respect to components and structure. However, this last criticism is made from the viewpoint of a person working in the field and this detail could easily confuse the general public. The only important long term weakness is the reliance on conceptual designs to illustrate dwelling types for the various regions, even though they show fairly good detailing in some cases, rather than drawings from actual dwellings.

One should remember that this book was written for the general public, and for this purpose, it can be recommended as introductory material on the building design concepts applicable to solar heating and cooling systems. Also, persons working in the field will find it interesting and enjoyable professional reading, possibly learning something new as well as the leisure enjoyment.

-Arthur C. Meyers III.