un appareil mis à la disposition du public par les télécommunications. Cet appareil sera dans le coeur de la maison tant pour la gestion que pour la communication avec l'extérieur.

TABLEAU I. Lien entre les capteurs et les fonctions à assurer

| | Confort | Sécu-rité | Régu-lation | Comp-tage | Effrac-tion | Incen-die | Program-mation | Eclai-rage |
|---|---|---|---|---|---|---|---|---|
| Temp. ext. | | | x | x | | | | |
| Temp. amb. | | | x | x | | x | | |
| Temp. eau chauffage | | x | x | x | | | | |
| Temp. eau sanitaire | x | x | x | x | | | | |
| Conditions extérieures | | | x | | | | | x |
| Ouvertures fenêtres | x | | x | | x | | | |
| Ouvertures portes | x | | | | x | | | |
| Détecteurs fumée | | | | | | x | | |
| Horloge | | | | | | | x | |
| Compteurs | | x | | x | | | | |
| Détecteur de présence | x | | | | x | | | x |
| Cellules | x | | | | | | | x |
| Commandes | x | x | x | x | x | x | x | x |



# A Passive Solar Heating System with Microprocessor Control

Andrew F. Rose

Composite Building Products
Post Office Box 325
Greeley, CO 80632, USA

KEYWORDS

Digital Control System, Energy Conservation, Energy Management and Control Systems.

ABSTRACT

A microprocessor was designed to monitor and regulate admitted irradiation and heat transfer on a spatiotemporal basis. Variables included in the firmware are: (1) daily change in declination, (2) 20 minute change in azimuth and altitude, (3) ambient conditions, and (4) energy storage throughout the diurnal cycle. The design permits maximum conversion of solar energy to a useable form with intrinsic construction features and with automatic adjustment of system components. A direct current source powers the low energy-consuming Data Collection Platform (DCP) as well as each system component. A battery array is maintained at full charge by a photovoltaic array, hence, a self-contained system. Electromechanical devices, controlled by the DCP, operate window shades and operate fans for heat distribution. This paper presents design considerations for system optimization. Considerations include an evaluation of household energy needs at various latitudes, incorporation of different building materials, and a description of the program ENVIREG.

Système passif de chauffage solaire
avec contrôle par microprocesseur

Andrew F. Rose

Mots clés:

Système de contrôle numérique, Economies d'énergie, Systèmes de gestion et de contrôle des dépenses énergétiques.

Résumé:

Un microprocesseur a été conçu pour gérer et réguler le rayonnement thermique et les transferts de chaleur sur une base spacio-temporelle. Les variables prises en compte sont les suivantes: (1) le changement journalier de déclinaison, (2) un changement d'azimuth et d'altitude toutes les 20 minutes, (3) les conditions ambiantes et, (4), l'accumulation de chaleur durant le cycle diurne. La conception permet la conversion maximum de l'énergie solaire sous forme utilisable, grâce à des caractéristiques intrinsèques de construction et à un réglage automatique des composants du système. La source d'énergie directe déplace la Plateforme Collecteur de Données (DCP) à faible consommation d'énergie, ainsi que chacun des composants du système. Un ensemble de batteries est maintenu en pleine charge par un ensemble de cellules photovoltaïques, composant par là, un système autosuffisant. Les extensions électro-mécaniques, contrôlées par la DCP, actionnent des persiennes orientables et des ventillateurs de distribution de la chaleur. Cette communication présente des considérations pour l'optimisation du système. Ceci inclue une évaluation des besoins énergétiques d'une habitation sous différentes latitudes, la prise en compte de divers matériaux de construction et une description du programme ENVIREG.



## INTRODUCTION

"Each year the sun drenches the United States with 500 times more energy than we consume. Solar energy could easily meet 20 percent of our energy needs by the year 2000."[1] To help meet our energy needs, we must understand in greater detail the natural and artificial environment.

This paper reviews solar thermal engineering concepts and introduces a method to optimize building operation. Unlike conventional control systems, the new microprocessor uses photovoltaic cells to generate electricity, providing power for all system components. To design an optimum hybrid active/passive solar heating system we must apply all our knowledge of natural thermal processes and behavior of building materials. Current efforts are generally devoted to low-cost components and improvement of thermal efficiency. Hopefully, in the near future, a typical house will maximize use of material properties of the structure; as an enhancement it will include an electronic control system to monitor and make adjustments for environmental changes. Software to control building performance has been developed by industry, but the details of algorithms are not generally public domain software; this paper presents a control algorithm. Five major sections are presented: (1) Geographical considerations, (2) Intrinsic construction features, (3) Hardware, (4) Software, and (5) Conclusions. Each section will explain in general terms the design considerations to be followed by the professional.

## GEOGRAPHICAL CONSIDERATIONS

Climate varies at each location on the earth's surface in part due to latitude, altitude and topography. At each latitude the thickness of the atmosphere parallel to the sun's rays varies; direct radiation passing through the atmosphere is attenuated by clouds, turbidity and air-borne pollutants. Scattering theory suggests that water drops, crystals or particles produce diffusion of light passing through the atmosphere, reducing terrestrial radiation levels. The amount of radiation passing through a cloud varies markedly with its optical thickness. Low level clouds when reaching a thickness of 600 m allow no direct radiation to pass through and medium level (altocumulus) clouds only pass a small fraction.[2] Therefore, the frequency of cloud occurance is of value when assessing the potential for heating by natural means. Macroclimates, at the same latitude, can vary if mountains, coastline or other water bodies are nearby. Mountains directly influence irradiance due to the higher elevation. At higher elevations there is less scattering and absorption within the atmosphere; however, the greater intensities of direct solar irradiance are often overcompensated for by the loss due to geographic obstructions and orographic and convective cloud cover.

Slopes and valleys receive less radiation in the morning and evening due to delayed sunrise and/or early sunset. Valley fog can form and remain for long periods of time, particularly during winter. Mountain-specific factors include longer snow cover, wind effects and obstructions in the solar window.

Coastal or water areas affect the macroclimate. Sea breeze and cloud/fog formation due to natural suppression of convective cloud development are characteristics of areas near water bodies. Large variability is seen in thermal gradients near coastlines, in part due to cloud cover, wind, ocean currents and pollution. Urban areas, where particulate concentrations are high, show reduced insolation of approximately 5-10 percent.

These geographic considerations explain why we can have wide climate variations at similar latitudes. For example, at the equator in Ecuador, South America, there are mountainous areas with severe climates while in Indonesia, at the same latitude, the climate is very mild. Generally, within 30 degrees of the Equator, cooling is the main concern while at the mid-latitudes heating is of concern.

## INTRINSIC CONSTRUCTION FEATURES

When man began construction of permanent or long-term dwellings careful planning allowed use of natural features to provide greater comfort. Historically, in arid regions earth shelters, or soddies, provided insulation and south-facing cliff dwellings were built which gained heat during winter and provided shade during summer. In the tropics houses are raised above the ground surface to improve ventilation while in the Arctic igloos include a tunnel, or airlock, to reduce convection. Through time man has developed to use a greater variety of materials in an ever more complex arrangement with the goal being to improve comfort levels. Of primary concern in the built environment is the inside temperature, either raising it or lowering it.

The science of thermal load dynamics seeks to understand the heat transfer dynamics of radiation, convection and conduction at relatively low differentials that characterize buildings heated and cooled by natural means. Various building codes have been enacted, restricting type and placement of building materials. In the Uniform Building Code a chapter is included on Energy Conservation in New Building Construction. The purpose is "to regulate the design and construction of the exterior envelopes and selection of heating, ventilating and air-conditioning, service water heating, electrical distribution and illuminating systems and equipment required for the purpose of effective conservation of energy within a building."[3] The Code for Energy Conservation in New Building Construction is another set of guidelines promulgated by national and international organizations.

Orientation and landscaping can lessen the energy consumption within a building. Siting with regard to local topography can influence the energy use in a dwelling. The building shell should be insulated on all exposed surfaces, including the ground, preferably with R-11 floors, R-19 walls, and R-22 ceilings. Glazing located on the south-facing walls will transmit, reflect and absorb solar radiation. The goal in glazing technology, for windows as a solar collector, is to maximize transmittance while reducing the reflectance and absorptance.



Conduction losses through windows vary depending on the temperature differential and emissivity of the window material. Insulated glass is marketed in two forms: soft-coat, in which a coating is vacuumm-deposited, or hard-coat, which is made by a pyrolitic process-the low-e coating, typically metal oxide, is fused to the glass surface. By 1990, double pane windows with low-e hard coat will yield a U-value approaching 0.32 $W/m^2 \cdot {}^oC$.[4] To further reduce heat losses, a series of vertical-axis shutters are positioned over each window. Of light construction and narrow width, each shutter rotates at $15^o$/hour, tracking the path of the sun through the sky. At night the shutters close, forming an air-tight seal. The drive mechanism at each window is a direct-current shunt moter with light gauge cord coupling between shutters.

Reflectors have several applications in buildings. Specular reflectors, usually of polished aluminum, located near windows or solar panels can concentrate the sun's rays; diffuse reflectors, such as a white matte surface, direct light evenly over a large area and can enhance daylighting.

Sun-tracking involves rotating a solar (photovoltaic) panel or concentrator throughout the day. Performance is increased by up to 35 percent above stationary systems. Passive trackers operate by electric motor or, of recent emphasis, by Freon vapor hydraulic actuators. A hydraulic-pressure system is purely mechanical; as the sun heats the liquid Freon it changes phase to a gas, increasing pressure to drive a cylinder connected to a mechanical linkage. Accuracy is somewhat limited during overcast periods, but commonly the panel will maintain an angle of incidence of less than two degrees.

Mass within or as a component of a building has the ability to store and release heat through natural convection and radiation. The ability of a material to store heat is expressed in terms of energy per unit mass or, preferrably, energy per unit volume. A stabilization of indoor temperature is the desired result. Materials with high heat capacity include concrete, brick and tile. Vents and ductwork move heated air to living areas or to the mass.

Solar Panels include a wide variety of devices to capture and use the sun's energy. They include closed loop systems with air or liquid as a fluid, concentrators which focus the sun's rays along an axis or to a point and photovoltaic cells which convert the sun's energy directly into an electrical form.

## HARDWARE

An 8-bit microprocessor was designed as a controlling system with feedback from various sensors. The circuit includes a central processing unit, address decoder, temperature-compensating crystal oscillator clock, and analog to digital decoder. The off-the-shelf machine is referred to as a data collection platform (DCP). The DCP is interfaced directly to standard RS 232 American Standard Code for Information Interchange (ASCII) terminals.

The complementary metal oxide semiconductor is capable of continous operation with an average power consumption of 120-375 milliwatts (10-30 milliamps at 12.5 volts). Power consumption is 7 milliamps while scanning sensors and peak power is 3 amps. The entire system, including all operated devices in the building, are direct current operated. Lead-acid batteries are the most common power source, typically 20 to 50 Amp hours capacity each. Two types of lead-acid batteries in use include liquid electrolyte-calcium alloy grid and sealed gel electrolyte. The first type is most common for several reasons. First, these cells have a greater volume and concentration of electrolyte which increases the ultimate capacity; also, preventing freezing of the cells if they reach a deep discharge condition. Secondly, the state of charge can be determined by measuring the specific gravity of the electrolyte. This is of benefit if the solar panels have been marginally sized or are subject to much shading. The state of charge can be observed for several months and compared with the power-supply analysis. Thirdly, these batteries can last 15 years or more and perform better in cold climates. Battery capacity, in ampere hours, is not a fixed capacity and is dependent upon the rate of depletion, operating temperature and the final cell volt at which the battery is considered depleted. Charger regulators between the solar panel and battery assure the charging voltage remains above the float voltage. Liquid electrolyte lead-acid batteries require float voltages of 14.1 to 14.5 volts.

The float/charge voltage to maintain batterys at full capacity is supplied by photovoltaic panels. Photovoltaic chargers are relatively maintenance free, simple to install, highly reliable and reasonably priced. Four technologies exist: flat-plate crystalline silicon, high efficiency concentrators, thin-film materials, and new concepts, materials and systems. In 5-10 years flate-plate silicon cells with a small or no concentration of solar flux will be the standard.[5] Costs per peak watt of photovoltaically-derived power have dropped from $20 (U.S.) in 1977 to $6-$8 today. To compete with U.S. bulk power markets, prices must go below $1 per watt. Generally, 32 to 36 cells Cells are connected in series to accumulate the individual voltages to the required float voltage. A blocking diode between the cells and battery array is like a one way valve, preventing current flow through the cells during the night.

Sensors collect the analog value of temperature and solar irradiation. The sensors are located within and outside the building structure.

## SOFTWARE

Realtime analysis of environmental conditions permit optimum operation of building components. These devices include vertical-axis shutters, fans and closed-loop solar collectors. Software is contained on Read Only Memory (ROM) and is designed to be computationally intensive. The user enters the parameters: present date and time, latitude, and longitude. These parameters, as well as realtime variables, are stored in Random Access Memory (RAM).



Sensors, or input devices, are sampled on a twenty minute interval between time of sunrise and time of sunset. Rational behind the program, labeled ENVIREG, is based upon celestial astronomy and, to a lesser extent, proven methods.
A description of the algorithm, as shown on Figure 1, will now follow. The described process is for latitudes north of the equater; to use the flowchart for southern latitudes, declination and azimuth values will differ. After midnight each day, the daily declination, time of sunrise and time of sunset are calculated and stored in RAM. When the time of sunrise is passed, the azimuth is calculated, being measured clockwise from true north. All ensueing calculations are performed with changing values of azimuth, and sensor readings and are stored in RAM.

A branch, or conditional, is introduced to change the program flow if the azimuth is less than 90 degrees, thus indicating a sunrise north of due east. This occurs in summer months and east-facing shutters are opened to enhance daylighting during early morning hours. When the azimuth does reach 90 degrees, or is greater than 90 degrees at sunrise, south-facing shutters are set and powered. These shutters, as previously described, are vertically inclined and rotate at a constant rate of $15^{o}$/hour

An internal clock counter sets the first sampling time at sunrise plus 20 minutes. This counter is designed so that sampling of data will occur at 20 minute intervals throughout the day; in the event solar irradiance, as measured by the pyranometer, falls below a threshold value for 40 consecutive minutes, south-facing shutters will be closed. When the radiation level rises above the threshold, shutters are repositioned to admit radiation.

A further branch occurs after 12:00 noon to allow operation of an air exchange fan. This fan moves solar-heated air in a sunspace or clerestory to a high heat capacity material such as brick or stone. The fan is activated when a temperature differential between the solar-heated air and heat sink is reached. Data collection interval for this branch coincides with that of other sensors at 20 minutes. In the event of a sunset north of due west, west-facing shutters are opened. At sunset, program flow branches out of the control loop and the date is incremented by one.

Variations on this idealized mode of operation are possible, the goal in the algorithm is to operate a building for maximum solar gain with little or no human intervention.

## CONCLUSION

This report discusses natural and artificial resources as applied to a hybrid active/passive heating system. Known behavior of the material, thermal and computer sciences allows design of an optimal control system. Specific technology which will expand in practical applications include: (1) glazing with selective coatings to reduce heat loss, (2) direct conversion of solar energy to an electrical form, (3) sun-tracking systems of strictly mechanical nature, and (4) microprocessors to operate conventional heating, ventilating and air conditioning systems.

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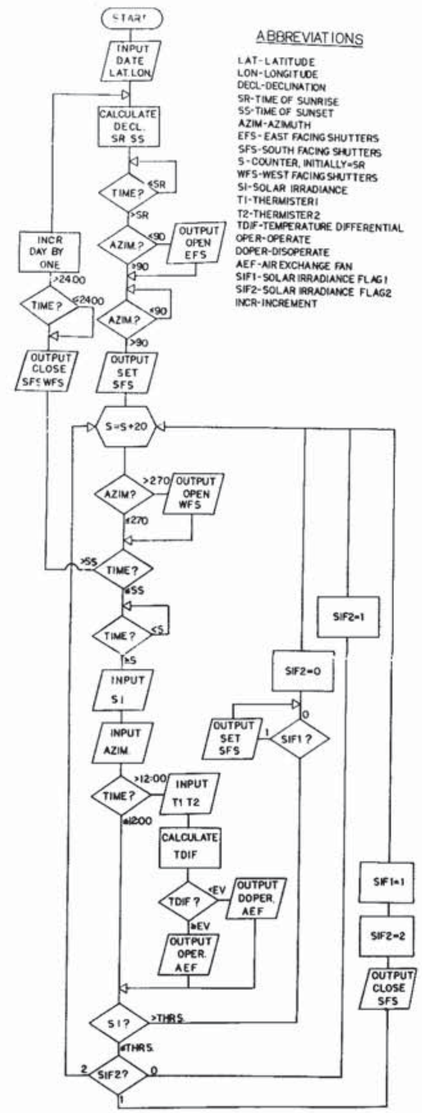


FIGURE 1