LA-UR-87-1531

CONF-8705122--1

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36.

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LA-UR--87-1531

DE87 010105

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SUBMITTED TO: International Energy Agency Solar Heating and Cooling Task X
Expert's Meeting
Tokyo, Japan
May 11-13, 1987

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EVALUATION OF MATERIALS BY THE ENERGY YIELD OF AN ACTIVE SYSTEM

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BACKGROUND

The suitability of materials for solar energy applications is often evaluated according to the engineering properties of the materials, such as yield strength, durability, or maximum operating temperature. However, the use of different materials can affect the energy yield of the solar energy system. It is therefore desirable to estimate the impact of new materials on the energy yield of systems. This paper will review the energy impact of materials on active systems for hot water and space heating of buildings. A separate paper in this conference will review impacts for passive systems. The energy impacts of absorbers, heat transfer fluids, and thermal storage materials on active systems are well understood, and will be described only briefly. The study of energy impacts of glazings has just begun, and initial results will be presented below.

ABSORBERS

Selective absorber coatings for flat plate collectors and for evacuated tube collectors are commercially available in many countries. These coatings usually have emissivity (ϵ) near 0.1, and absorptivity (α) greater than 0.9. Little additional energy yield would result from additional reductions in ϵ or increases in α. Altering the absorber coating usually produces changes in both α and ϵ. A person who develops new absorber coatings may need to know if changes in α and ϵ cause a decrease or an increase in energy yield of the collector. The impact of α and ϵ on energy yield depends in a complicated way on the operating conditions, so a single rule does not apply to all cases[1]. As a rough approximation for solar energy systems used in buildings, one should examine the ratio of the changes in α and ϵ, $\Delta\alpha/\Delta\epsilon$. For insolation near 750 W/m^2, glazing temperature near 40 °C, and absorber temperature near 80°C, the energy yield will usually be increased if $\Delta\alpha/\Delta\epsilon$ is > 0.5, and decreased if this ratio is < 0.5.

HEAT TRANSFER FLUIDS

The common heat transfer fluids used in active systems are water, water-glycol solutions, oils, and air. Water and water solutions provide the best heat transfer. A small reduction in collector efficiency occurs when oils are used. Oils provide protection against freezing, corrosion, and boiling, but require more pumping power. Collectors using air as a heat transfer fluid have roughly 20% lower efficiency than collectors using water. Rock bins usually provide the thermal storage in air systems for space heating. The temperature stratification in rock bins is usually much better than the stratification in water tanks used for thermal storage in liquid systems. Therefore, the energy yields of liquid and air systems are often comparable, in spite of the lower collection efficiency of air systems. The use of air requires much larger electrical power for circulation of the fluid than the use of water. The use of air eliminates the problems of freezing, corrosion, and boiling, and reduces the concern with leaks.

In a few commercial systems, the heat transfer occurs by evaporation of a refrigerant in the collector, and condensation of the refrigerant vapor in the thermal storage unit. Boiling heat trasnfer provides a collector efficiency slightly larger than that obtained with water, and a significant reduction in pump size and pumping power. Current research on refrigerant-charged systems proves that these systems can utilize the vapor pressure to return the condensed liquid to the collector, eliminating the need for an electrically powered pump[2,3].

THERMAL STORAGE MATERIALS

In a system using sensible heat storage, the temperature must rise as energy is stored, resulting in decreased collector efficiency. The energy yield of a system should be increased slightly if a phase-change material (PCM) is used for thermal storage because the storage remains at one temperature. However, the major effect of PCM storage is to reduce the volume of storage. Because the thermal conductivity of the PCM is usually low, the material must be encapsulated in containers with large surface/volume ratio to provide adequate heat transfer between the moving fluid and the PCM.

GLAZINGS

At Los Alamos, we are currently studying the energy benefits of various glazings. In general, any assembly of materials into a glazing for a flat plate collector can be represented by three characteristic numbers. It is most convenient to consider the properties of the glazing-absorber combination, although the selective properties of the absorber have little influence if the glazing has large thermal resistance. The glazing (or glazing-absorber combination) can be described by its thermal conductance (U_t), its solar heat gain coefficient at normal incidence (SHG_n), and by the incidence angle modifier (K) of the solar heat gain coefficient. The U_t of the glazing/absorber combination is the top heat loss coefficient for the collector. For many collectors, the total heat loss coefficient (U_L) is approximately $1.6U_t$. In our study we assume that the back and edge insulation of collectors will be increased so as to maintain the ratio $U_L/U_t = 1.6$ when improved glazings are used.

The solar heat gain coefficient represents the fraction of solar radiation incident on the collector that is deposited in the absorber. This is often regarded as the transmittance-absorptance product. However, the solar heat gain coefficient includes the effects of transmission <u>and</u> absorption within the glazing unit. Composite glazings with infrared-reflective layers or other internal materials may absorb some radiation within the glazing, and a portion of the absorbed energy is conducted inward to the absorber. At an angle of incidence, θ, the solar heat gain coefficient is given by:

$$SHG(\theta) = SHG_n \cdot K(\theta),$$

in which

$$K(\theta) = 1 - b_o(1/\cos(\theta) - 1).$$

This form of the incidence angle modifier is used for flat plate collectors with layered glass glazings, and we assume it will also be appropriate for other glazings. The term b_o is a constant for each glazing. The table below shows sample values of U_t, SHG_n, and b_o. We are investigating the total system energy yield as a function of these three parameters.

PROPERTIES OF SAMPLE GLAZINGS

GLAZING	Single glass	Double glass	Multi film
ABSORBER	selective	flat black	flat black
U_t (W/m^2°C)	3.2	3.2	0.6
SHG_n	0.9	0.8	0.5
b_o	0.1	0.17	0.5?

The expression for the instantaneous energy yield of a collector is:

$$\dot{Q} = F_R(\Sigma\, SHG(\theta)\cdot I(\theta) - U_L(T_i - T_a)),$$

in which F_R is the heat removal factor (which depends on U_L), I is the incident insolation, T_i is the fluid temperature at inlet, and T_a is the ambient air temperature. The sum is over the three components: beam, diffuse, and ground-reflected radiation. Each component has its corresponding angle of incidence. The average efficiency for the year is the sum of energy yield for all hours of operation divided by the total annual incident insolation. It can be shown that the average annual efficiency (η_{yr})should have the form:

$$\eta_{yr} = F_R\cdot SHG_n(C_1 - C_2 b_o) - C_3 U_L ,$$

in which C_1, C_2, and C_3 may depend strongly on climate and weakly on the collector parameters.

The linear behavior of η_{yr}/F_R as a function of SHG_n is shown in Figures 1 and 2 for the city of Albuquerque, which has a warm, sunny climate. In Figures 1 and 2, it can be seen that, at fixed SHG_n, a collector with $U_t = 0.6$ W/m^2°C has better energy yield than a collector with $U_t = 3.2$ for all $b_o > 0.4$. It can also be seen that decreasing U_t from 3.2 to 0.6 W/m^2°C has the same effect as increasing SHG_n from 0.7 to 0.9. This provides an initial estimate of the benefits of relative changes in U_t and SHG_n. It appears that each reduction of U_t by a factor of two would permit a reduction of SHG_n by approximately 0.1, for equal energy yield. For the climate of Albuquerque, $0.80 < C_1 < 0.95$, $0.3 < C_2 < 0.5$, and C_3 is in the range 0.03-0.05°C m^2/W. We are attempting to find simple rules for C_1, C_2, and C_3 so that the energy impact of almost any glazing can be easily predicted for any climate.

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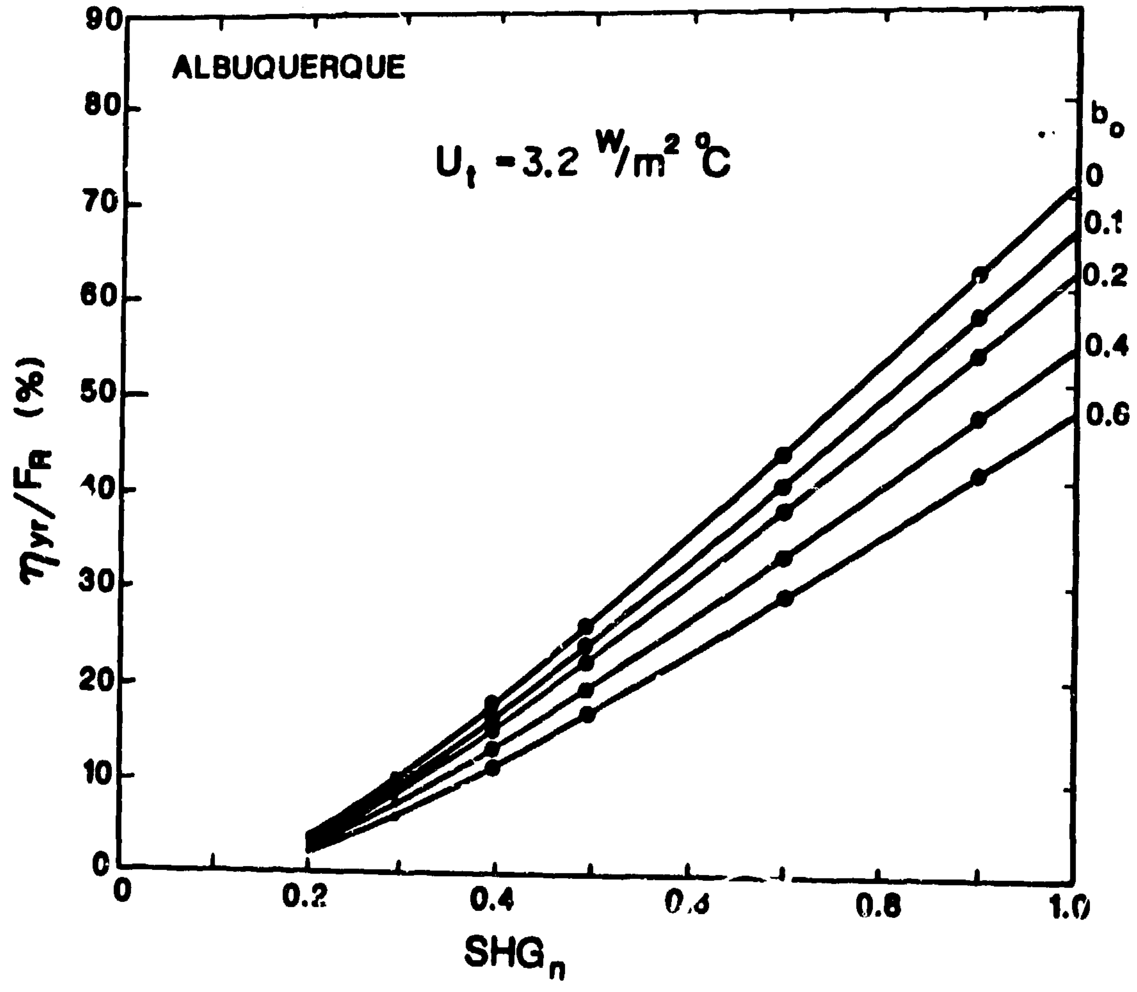

Figure 1. Average annual system efficiency divided by F_R as a function of the solar heat gain coefficient at normal incidence. The inlet temperature is 50°C and U_t is 3.2 W/m^2°C.

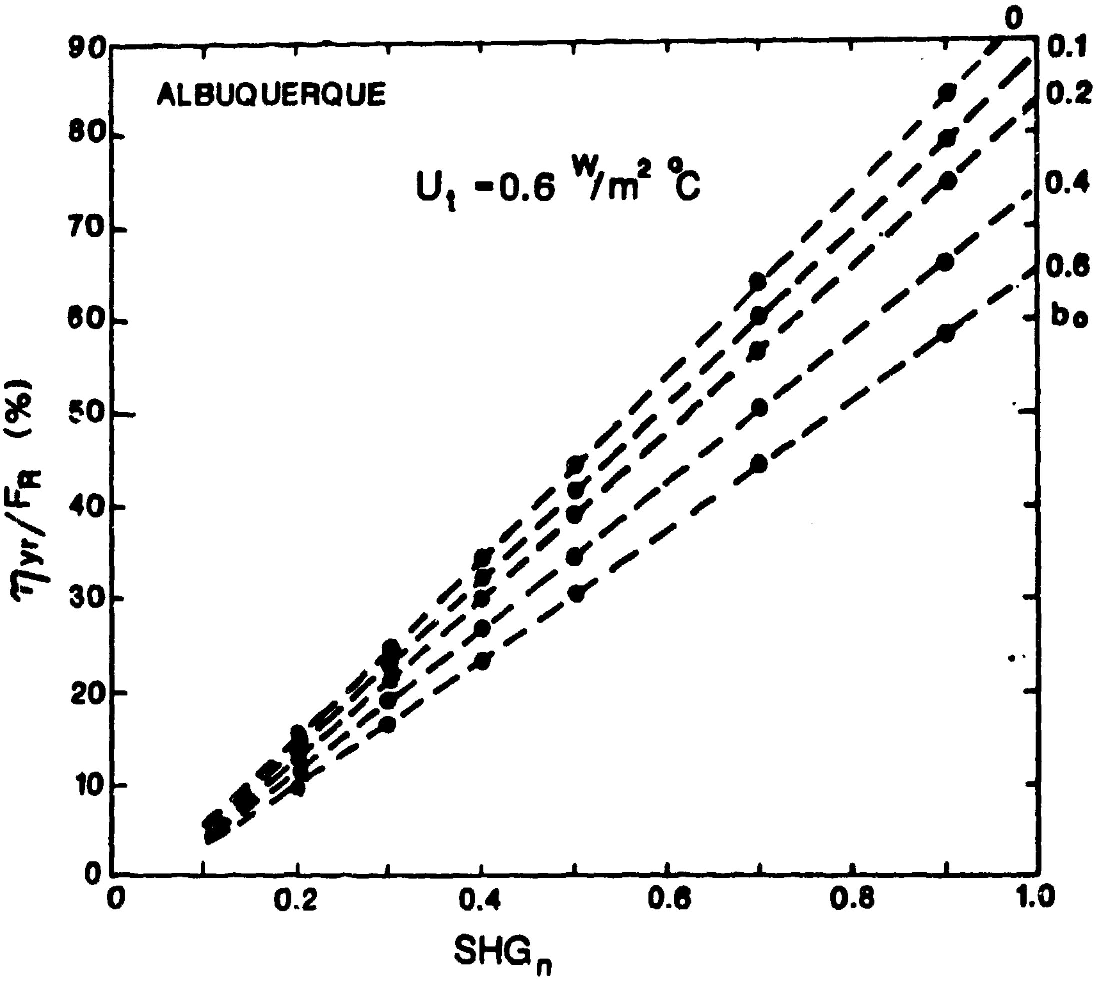

Figure 2. Average annual system efficiency divided by F_R as a function of the solar heat gain coefficient at normal incidence. The inlet temperature is 50°C and U_t is 0.6 W/m^2°C.