Extended Abstract for ASES 2003:
Modeling of Unglazed Collector Systems and Initial Results for Albuquerque, NM

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This paper details modeling assumptions and simulation results for an unglazed collector system supplying domestic hot water (DHW), space heating (SH) and space cooling (SC) loads. A similar system was described in (Baer, 2001), with the main difference here that the DHW load is added to the system.

Model description

Figure 1 gives a schematic diagram of the system model. The unglazed collector sub-model here is described in (ISO-9806-3) and (Harrison 1996). Wind and infrared exchange are explicitly accounted for. The collector loss coefficient is expressed as:

$$Fr(Ul) = b_0 + b_1 * v_{wind}$$

The optical gain term is expressed as:

$$Fr(\tau\alpha)_n = a_0 - a_1 * v_{wind}$$

This approach for parameterizing $Fr(\tau\alpha)_n$ is suggested by (Harrison 1996); in (ISO-9806-3), $a_1 \equiv 0$. Short wave radiation and (negative) long-wave radiation are added to yield the "net radiation" to be used in the traditional HWB efficiency equation. The "local wind", measured 10 cm above the collector, is the wind velocity prescribed in ISO-0806-3, used in the regression of the coefficients a_i, b_i, and to be used in simulations. However, the wind in TMY files is generally that measured at 10m height, typically at an airport with flat, clear surroundings. It was assumed that local/TMY wind velocity has a constant ratio of 0.3. Results (a_i, b_i) for collector FA357 in (Harrison 1996) were used here.

The collector is linked to a hot storage and a cold storage tank. Each tank had a volume of 80 liters/m2-col, used 5 nodes [moderate stratification], and had R10 insulation. The system stores solar heat during the day and radiative/convective "coolth" at night, when it is favorable to do so. The storage tanks are linked to the house through fictitious heat exchangers with a specified parameter ΔT_Hx. ΔT_Hx sets the (constant) temperature difference between zone air temperature and heat exchanger outlet temperature. Flow rate on the house side of the tanks is computed as that needed to meet the current load, subject to a maximum flow limit (800 lit/hour for the runs here). A lossless instantaneous water heater with unit efficiency is the DHW auxiliary.

The house model is intended to be simple but realistic for load timing and magnitude. It has floor area of 2000 ft2, with square footprint. The walls are nominal R19, and ceiling R30. There are 360 ft2 of low-e double pane windows (18% of floor area), with equal amount at each orientation (N/S/E/W). Windows on S/E/W orientations have overhangs with 1 meter extension out from the wall, located 0.3 m above the top of the 3.2 m high windows. The roof was horizontal. The concrete slab floor has perimeter insulation. Air change was set to a constant 0.3 ACH. Besides wallboard and slab floor, a close-coupled capacitance of 2 Btu/ft2-F was assumed to account for "stuff" inside the building. Internal gains from equipment and people totaled 100,000 Btu/day. The heating efficiency and cooling COP were set to one; auxiliary energies can be interpreted as un-met load. There was no accounting for latent loads.

Model Results

Heating/cooling/DHW loads without the solar system were 22.6/25.0/16.7 GJ/yr., respectively. Figure 2 shows the annual auxiliary for DHW, heating, and cooling as the collector size is varied. Curves are shown for two different ΔT_Hx values, 1C and 5C. Roughly 2/3 of the DHW load is picked up at the smallest area of 5.84m2, with little space heating or cooling provided. As the area increases, the system meets more and more DHW and space conditioning load, albeit with the expected diminishing returns. The net and marginal efficiency of the collector in heating are shown in Figure 3. The largest system meets most of the total loads (~92%) in this favorable dry, sunny climate of Albuquerque with relatively moderate temperatures but significant heating and cooling loads. Monthly profiles will be shown for several collector sizes.

[Note: the climate comparisons will not be in this paper, but in an accompanying paper mapping performance geographically. Included here for interest] It is instructive to compare Albuquerque to other climates. Figure 4-6 compares the DHW, SH, and SC performance in three locations for small, medium and large collector systems, respectively. The largest DHW savings is always seen in Albuquerque, but the largest fraction of DHW load being met is always in Miami (warmer climate, with warmer water temperature and lower DHW load). Space heating savings in Albuquerque are much larger in Albuquerque than in Madison (space heating load is insignificant in Miami). This is undoubtedly related to the unglazed collector's utilizable energy decreasing rapidly as ambient temperature decreases relative to the minimum load temperature, especially when the wind is blowing. Cooling presents a more complex picture. At the larger collector sizes, significant cooling is supplied in all three climates. Albuquerque outperforms Miami in all but the largest collector size, despite having less than half the load. Nonetheless, there is significant cooling supplied in Miami. Examination of the monthly profiles for Miami, as shown in Figure 7, shows that most of the cooling in Miami comes in the winter months, due to ambient temperature dropping below cooling setpoint at night. A night ventilation cooling system may work nearly as well as the active system in this case, although there are moisture and latent load issues. It is clear that there are geographical/ climatic effects that will limit the potential market for "triple play" unglazed systems. Of the three sites, Albuquerque- with mild but real winters and dry, hot summers with cool nights- is by far a more favorable location, having overall fraction of load met at ~90% versus ~40% in the other two climates.

References:

Baer, S., "Passive Cooling and Drainback Heating with Unglazed Radiators/Absorbers – The Architectural Cool Cell" (TM)", Proc. ASES2001, May 2001, Washington D.C. Available ASES, Boulder, CO 80302, U.S.A.

Berdahl, P., and Martin, M., "Characteristic of Infrared Sky Radiation in the United States", Solar Energy Journal, Vol. 33, 1984. Pergamon Press.

Harrison, S. McClenahan, D., and Nielsen, V., "Performance of Unglazed Solar Collectors",…

ISO 9806-3: International Standards Organizations, Standard for testing of Unglazed Collectors,…

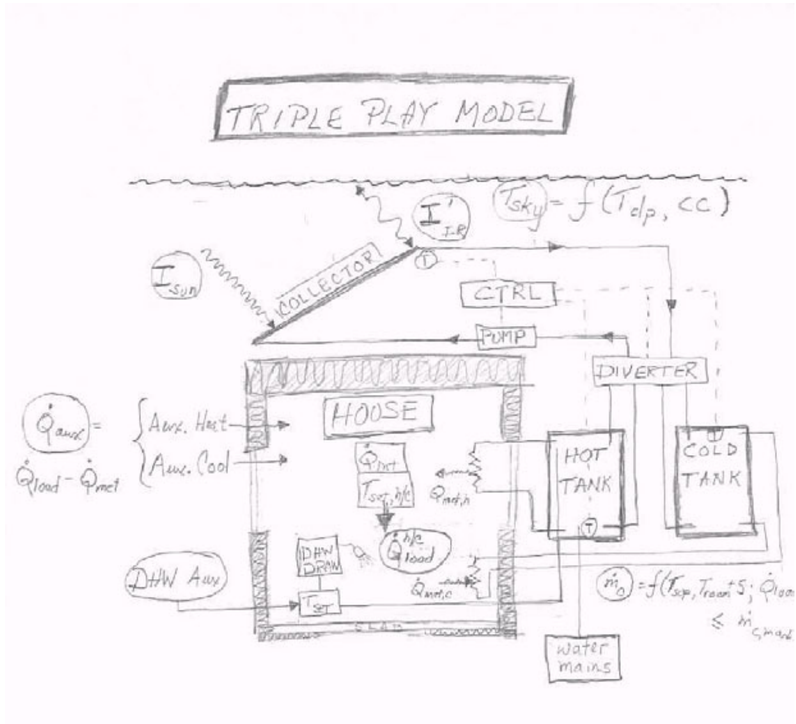

Figure 1. Schematic model of unglazed triple play system, as presented at 11/02 unglazed workshop. The 2000 ft2 house is square plan, with R19 walls, R30 roof, and 360 ft2 of double-pane low-e windows. The unglazed collectors feed into hot/cold tanks, which supply space heating, space cooling, and DHW.

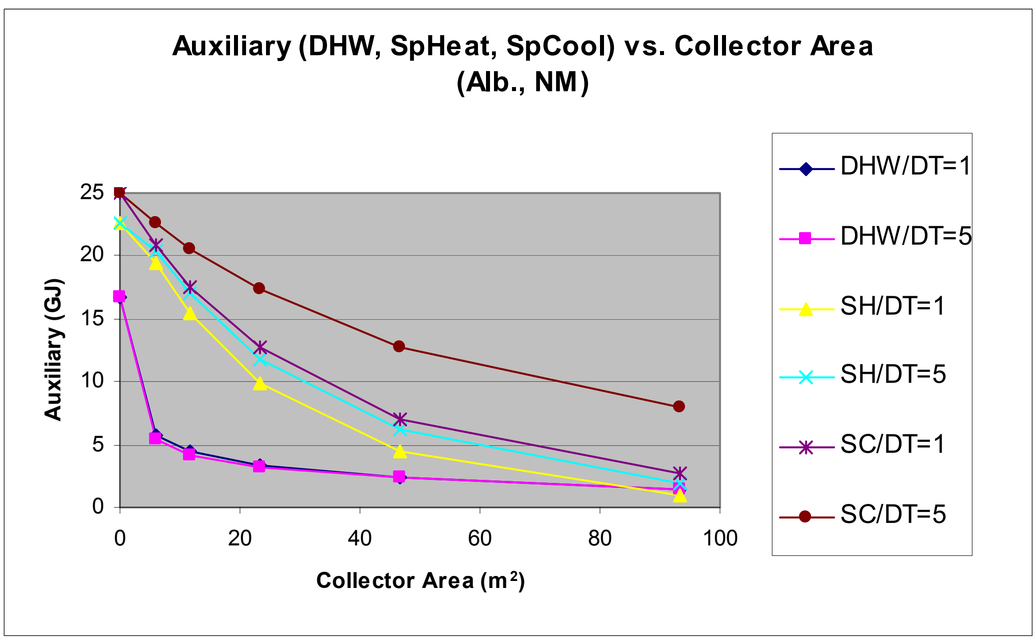

Figure 2. Total auxiliary energy versus collector area. Domestic hot water (DHW), space heating (SH), and space cooling (SC) are shown. DHW quickly “saturates”; heating and cooling decrease more slowly and evenly with increased area, although “diminishing returns” is clearly evident.

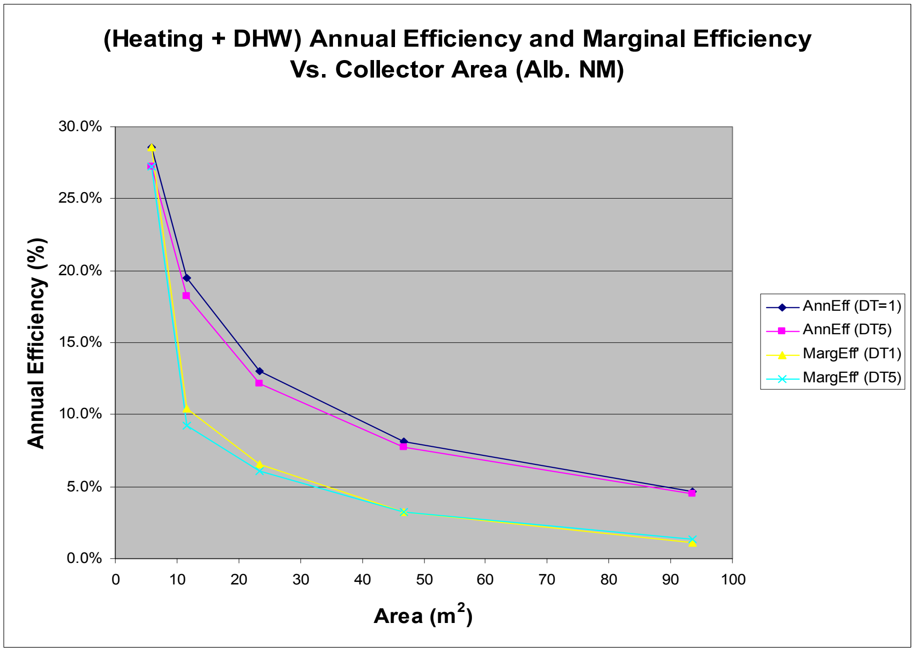

Figure 3. Annual efficiency and annual marginal efficiency versus collector area. Annual efficiency is defined as (total savings)/(total solar incidence), and annual marginal system efficiency is defined as (change in total savings)/(change in total solar incidence).

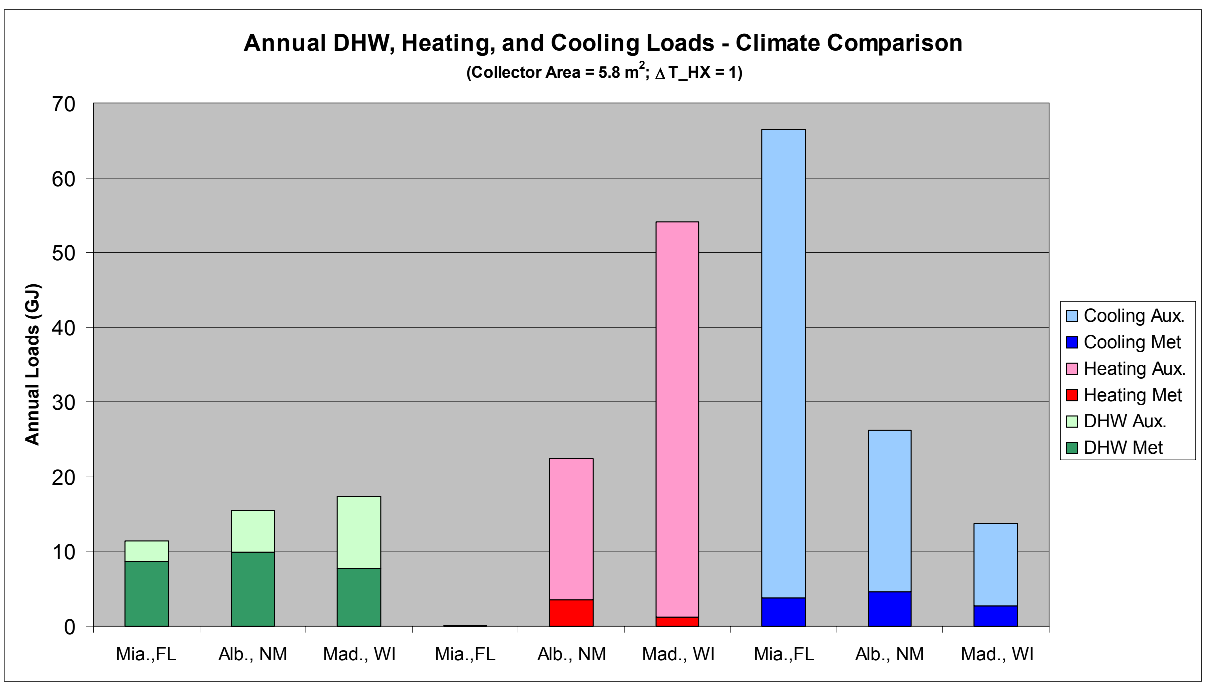

Figure 4. DHW, Heating, and Cooling Performance of the triple-play unglazed system in three climates. Climates are given at bottom. Collector area is small, 5.8 m2.

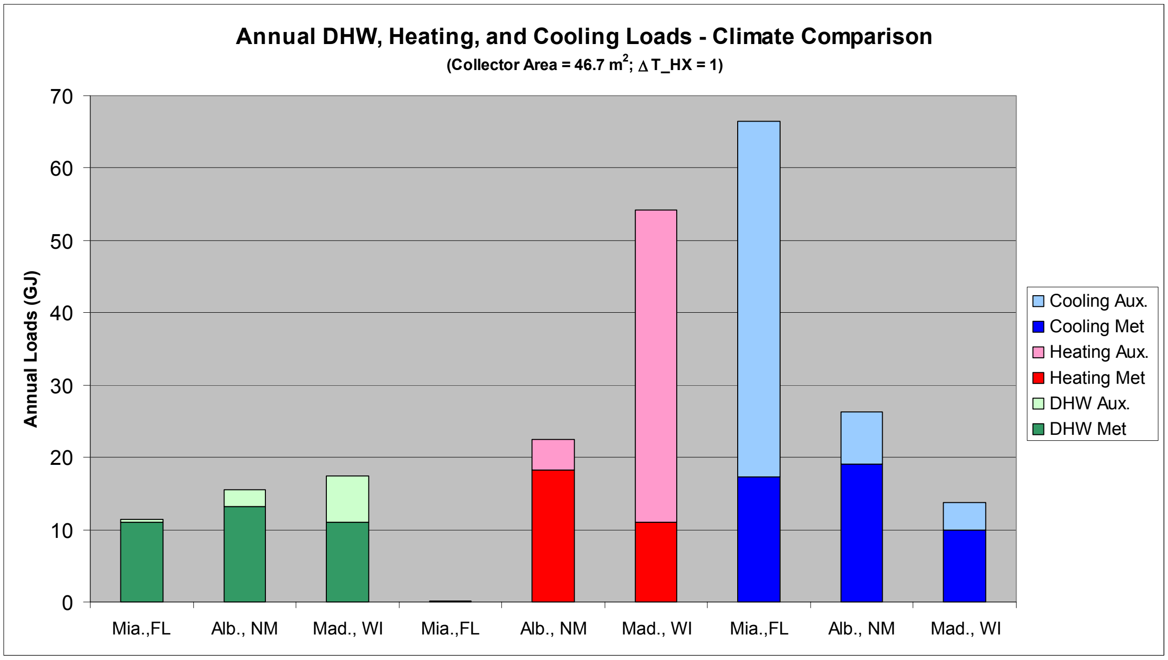

Figure 5. DHW, Heating, and Cooling Performance of the triple-play unglazed system in three climates. Climates are given at bottom. Collector area is fairly large, at 47 m2.

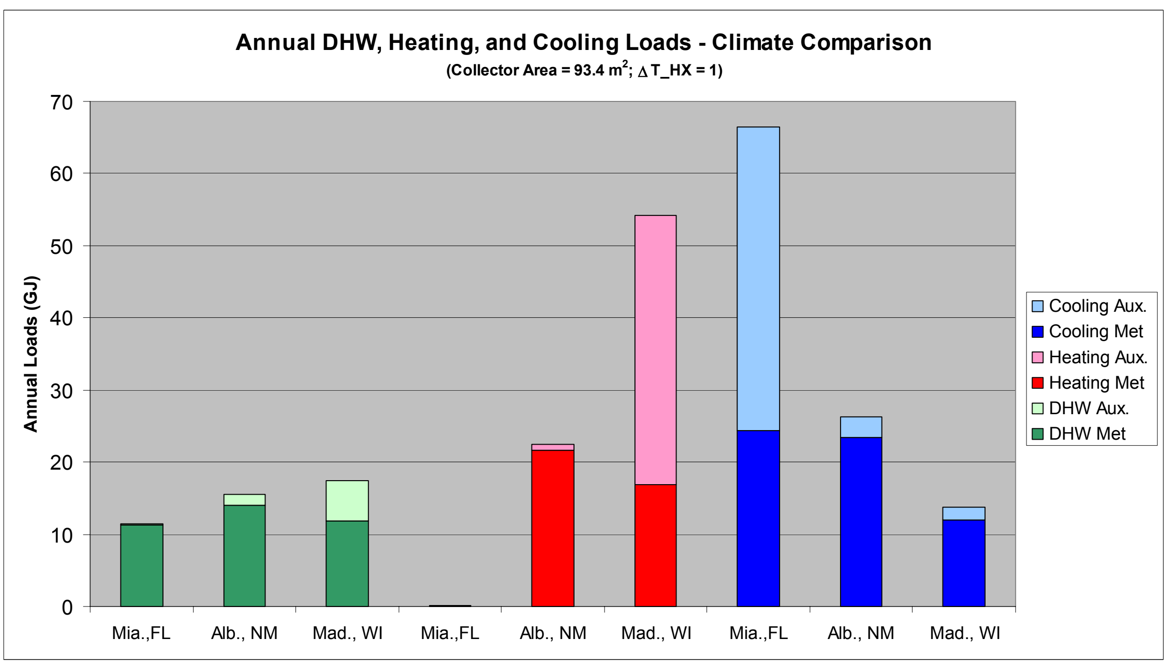

Figure 6. DHW, Heating, and Cooling Performance of the triple-play unglazed system in three climates. Climates are given at bottom. Collector area is largest simulated, at 93 m2.

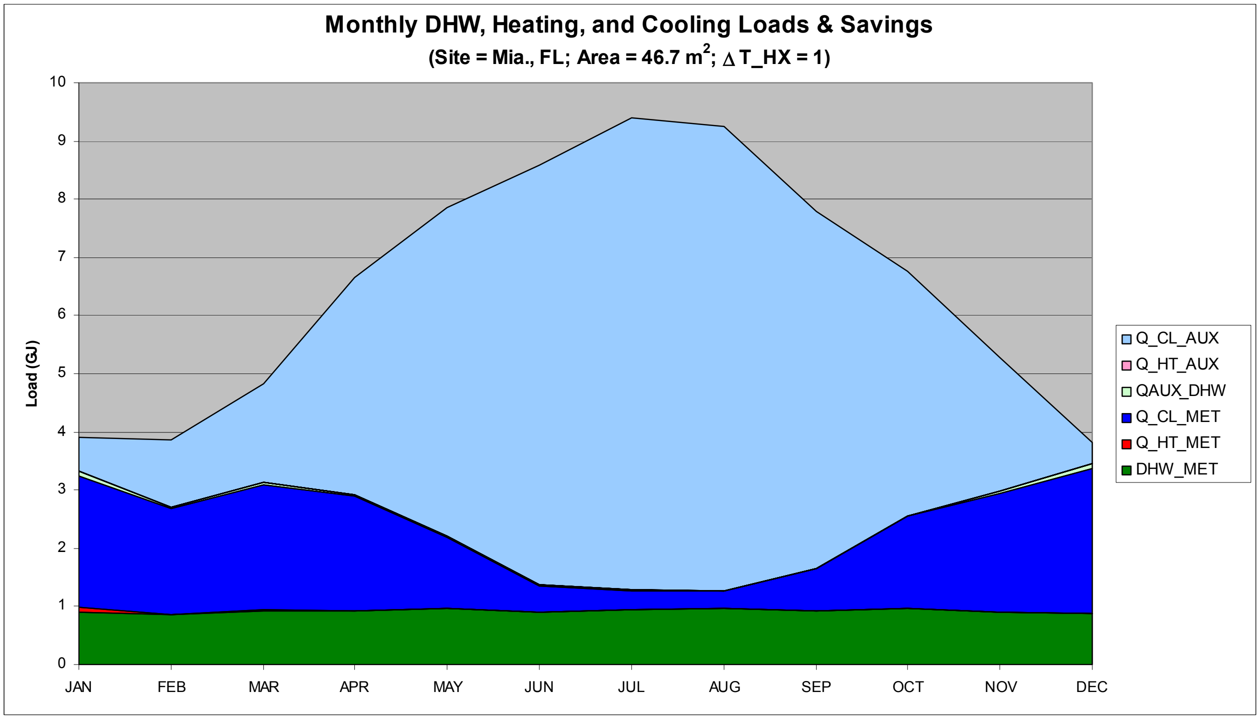

Figure 7. Monthly DHW, SH, and SC savings and auxiliary load in Miami, with 47 m2 collector. Note that almost no cooling is delivered in the June-September high-load months. Nearly all of the DHW load is met, and there is no heating load of consequence.