SOME LOW COST RESEARCH TECHNIQUES FOR USE IN DEVELOPING COUNTRIES

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ABSTRACT

Research of renewable energy is capital intensive. Many important research tools are out of the reach of many researchers in developing countries. This paper discusses some research equipment and techniques which can be acquired and implemented at relatively low cost.

INTRODUCTION

The oil crisis of 1973 produced, among other things, a tremendous upsurge in research on renewable energy sources, particularly solar and wind energy. Although the initial impetus has somewhat abated, much research is currently in progress in many countries of the world, including the developing countries. However, research is capital intensive and some of the important research tools and equipment like solar simulators, computing centres and data acquisition and processing systems are often beyond the limited facilities of some researchers in developing countries.

In this paper, examples are given of low cost research undertaken in the areas of: solar collector behaviour and testing on a solar simulator; data acquisition and processing; and computing.

SOME EXAMPLES OF LOW-COST RESEARCH

Small-scale solar collector and simulator

The solar simulator is used to determine the parameters of a solar collector or to obtain qualitative answers regarding test procedures, control strategy, etc. The analytical equations which describe the temperature history of the solar collector and tank indicate that the energy gain of a system, per unit collector area, is independent of the size of the system. Therefore, where the test is not to determine the parameters of an actual system the collector, hence the simulator, may be reduced by a factor of at least 10, resulting in the reduction of equipment costs by a factor of about 100. Furthermore, a special laboratory would not be required.

The small-scale solar collector system described by Munroe (1982) consists of a square copper plate 0.09 m^2 in area and about 0.8 mm thick, to which was soldered as heat exchanger a serpentine pattern of thin-walled copper tubing of internal diameter 0.32 cm. The plate was painted matt-black on the heat exchanger side and housed in a shallow wooden box 33 x 33 x 3.8 cm. The glazing on the front of the collector consisted of clear perspex 0.16 cm thick and the insulation on the back 1.0 cm thick sealed polystyrene foam.

The storage tank consisted of a 4-litre capacity plastic container, which was insulated by placing it in a larger cardboard box and filling in the spaces with styrafoam chips. A further length of thin-walled copper tubing, wound into a helix, served as a heat exchanger in the tank. A small electrically driven pump (of the type used by model aeroplane enthusiasts to pump fuel) was used to pump water in a closed loop between the heat exchangers in the collector and tank. Clear plastic tubing was used to connect the pump and heat exchangers in the loop.

Thermocouples inserted into the flow monitored the temperature of water entering and leaving the collector. Three further thermocouples monitored the temperatures at the top and bottom of the storage tank and the ambient temperature. The volume flow rate of water through the collector was measured using a small digital flow rate meter of the type marketed for measuring fuel consumption rates in cars. The output of the flow rate meter was a train of pulses with frequency proportional to flow rate.

The solar simulator consisted of a single, high intensity lamp (Thorn OM1000, CSI, 1000 watts). This provided a uniform intensity of about 967 w/m^2 at a distance of about 1.5m away. Table 1 shows a breakdown of costs for the small-scale system and simulator.

Work done using the small-scale system and briefly discussed below include:

1. Validation of an equivalent electrical circuit model of the flat-plate solar water heating system (Munroe 1980).
2. Transient testing of the flat-plate solar collector (Munroe 1983).
3. A method of determining the time constant of a flat-plate solar collector (Munroe 1981).

Equivalent electrical circuit model

In order to evaluate the performance of solar collectors, it is first necessary to establish the criteria of performance. These are based on the mathematical model of the collector. The best known model is that by Hottel and Whillier (1955). The model assumes zero thermal capacitance for the collector and expresses the energy output in terms of the incident radiation, the difference in temperature between the collector and the ambient air, and the collector heat loss coefficient.

The basic model of Hottel and Whillier was extended by Close (1967) to include a single thermal capacitance for the collector, referenced to the mean temperature of the collector plate. A transient model for the collector by Munroe (1981) assumes a single thermal capacitance for the collector, referenced to the mean temperature of the collector liquid. The transient energy balance equation for the collector may then be expressed as

$$q_u = \dot{m}C_p(T_o-T_i) = I\alpha\tau - U_1(T_1-T_a)-C_1dT_1/dt \tag{1}$$

The energy balance of the storage tank on a unit collector area basis will be

$$\dot{m}C_p(T_o-T_i) = U_2(T_2-T_r)+C_2dT_2/dt+U_L(T_2-T_L) \tag{2}$$

If an artificial heat transfer coefficient U_3 is introduced, defined as the mean heat transfer coefficient between the collector and storage tank, such that

$$\dot{m}C_p(T_o-T_i) = U_3(T_1-T_2) \tag{3}$$

substituting (3) in (1) and (2) and re-arranging in matrix form and taking Laplace transforms, gives

$$\begin{bmatrix} U_1+U_2+sC_1 & -U_3 \\ -U_3 & U_2+U_3+U_L \end{bmatrix} \begin{bmatrix} T_1(s) \\ T_2(s) \end{bmatrix} = \begin{bmatrix} I(s)\alpha\tau+U_1T_a+C_1Y_1(o) \\ U_2T_R+U_LT_L+C_2T_2(o) \end{bmatrix} \tag{4}$$

A solution to equation (4) for the special case where I is a constant or step function, as obtains on a solar simulator can be expressed as

$$T_1 = A_o+A_1\exp(-\delta t)+A_2\exp(-\gamma t) \tag{5}$$

$$T_2 = B_o+B_1\exp(-\delta t)+B_2\exp(-\gamma t)$$

where A_o, A_1, A_2, B_o, B_1, B_2, δ and γ are constants. One advantage of equation (4) is that it can be used to derive an equivalent electrical circuit for the system by inspection.

An equivalent electrical circuit for the typical closed loop, forced circulation, flat-plate solar water heating system is shown in Figure 1. A differential temperature controller has been added for completeness. In the equivalent circuit, voltage is analagous to temperature and current is analagous to heat flow. System simulation is reduced to determining the response of the circuit to any chosen time-dependent current input.

Transient collector test

A transient test for solar collectors requires a transient model for the collector and equation (1) is used for that purpose. The transient efficiency equation is given by

$$\eta_1 = \alpha\tau - \left\{U_1(T_1-T_a)+C_1dT_1/dt\right\}/I$$

$$= \alpha\tau - U_1\left\{(T_1-T_a)+kdT_1/dt\right\}/I \tag{7}$$

where $k = U_1/C_1$

The graph of η_1 vs $\{(T_1-T_a)+kdT_1/dt\}/I$ is a straight line similar to the steady-state collector line, with intercept $\alpha\tau$ on the η_1 axis and slope $(-U_1)$. To use equation (7) as a basis for transient tests, it is necessary to determine the value of k, the ratio of heat loss coefficient to thermal capacity. This may be obtained from a cooling test. If the collector cools from an initial temperature $T_1(i)$ to a final value $T_1(f)$ in time t (with the circulation pump turned off), then from Newton's law of cooling

$$\left\{T_1(f)-T_a\right\} = \left\{T_1(i)-T_a\right\}\exp(-kt) \tag{8}$$

which may be re-arranged to give

$$\ln \left\{ (T_1(f)-T_a)/(T_1(i)-T_a) \right\} = \ln(\Delta T/\Delta T_0) = -kt \qquad (9)$$

A transient test was carried out on the small test collector, connected up to the storage tank in the conventional configuration used for water heating. The result of the test indicates that the system is linear and the graph of $\ln(\Delta T/\Delta T_0)$ vs. t is a straight line with slope k. This value of k is substituted in equation (7) and the graph of collector efficiency η_1 vs. $\{(T_1-T_a)+kdT_1/dt\}$ is a straight line with intercept$\alpha\tau$ on the η_1 axis and slope $(-U_1)$.

Collector time constant

Equations (5) and (6) indicate that the time-dependent behaviour of the collector and storage tank is determined by two time constants, $1/\gamma$ and $1/\delta$. The time constant of the collector is $1/\delta$, where δ is a function of the parameters not of the collector only, but all the other parameters of the flat-plate solar water heating system. This dynamic collector time constant can be shown to influence only the very short-term ($\simeq$3 minutes) behaviour of the collector. The transient behaviour of the collector, however, is dominated by the dynamic time constant of the system, $1/\gamma$, which is of the order of several hours.

The dynamic time constant of the collector is directly proportional to the thermal capacity of the collector, but further simulation studies indicate that collector capacitance has very little effect on the daily or long-term performance of the solar water heating system.

Computing facilities

Most computing centres have mainframe computers with an extensive library of subroutines in Fortran which are readily accessible to users and this can provide formidable support in any research project. In the case of some developing countries, computing facilities may be very limited or entirely absent.

For those researchers who do not mind learning another computer language, ie basic, and are willing to develop their own programs in basic, then there exists a range of relatively inexpensive "home" computers which can provide some research support.

Two low-cost microcomputers which can be discussed from first hand experience are the Sinclair ZX81 and the Sinclair ZX Spectrum. The ZX81 is at the lower end of the computer market and a machine with 16 kilobytes (16k) of memory sells for about £70. A machine with 64k of memory, the maximum possible for an 8-bit computer, sells for about £95. Program storage is by ordinary cassette recorder, although special computer grade cassettes are available. Suitable cassette recorders are available at about £25-£30.

If printout of results is required, then the ZX81 can be interfaced to most of the commercially available printers. The printer currently available for the ZX81 at the lowest possible cost, called the Alphacon 32, sells for about £70. A small computing system incorporating many of the mathematical functions of larger computers and with storage and printout can be assembled at a cost of less than £200. An ordinary UHF television set is required to monitor the input and output of the computer. With this included, the total cost is about £250.

The ZX81 is however, not without its drawbacks which include:

1. very slow compared with the mainframes; computing times are measured in minutes, rather than seconds

2. not very many off-the-shelf programs are available for scientific computing; program must be developed by the user

3. double precision not available

4. high resolution graphics not available; with the exception of bar charts, good quality graphs cannot be drawn on the monitor

5. poor keyboard.

Some of the drawbacks of the ZX81 may be overcome by using a ZX Spectrum. The 16k machine costs about £90 and the 48k machine costs £130. Mass storage using floppy discs are available from about £240 for 200k of storage to about £280 for 800k. The Spectrum has its own inexpensive mass storage unit - the microdrive which starts at about £150 for 100k of storage, but this may not be suitable in all cases, since the storage unit may be damaged if turned on with the disc in position. The computer can also be connected to a wide range of printers. A 16k system with microdrive and Alphacom printer would thus cost about £310. The Spectrum offers very good high resolution graphics and has the advantage over the ZX81 that it can store the results of a program without having to store the entire program - a worthwhile feature when large volumes of data are to be stored. The Spectrum is still much slower than the mainframe computer and does not offer the double precision facility. An additional plus for the above microcomputers is that there are several magazines devoted exclusively to them which give good subroutines, hints on programing, etc.

The list of suitable microcomputers has of course not been exhausted and has been confined so far to the lower end of the computer market. One of the more popular up-market machines is the Apple II, with prices for a 48k machine with disc drive and printer starting at more than £1000. Where research funding is not a serious constraint, this category of machine may be considered, since there is a wider range of off-the-shelf computer programs available and the machine can be programed in Fortran and Pascal, as well as in Basic.

All the computations, simulations, analysis of collector test results, etc by the author which have been referenced in this paper were carried out on one or another of the three above-mentioned microcomputers. In addition, the author has served as convenor of a subcommittee which drew up the initial specifications for a microcomputing centre at the Federal University of Technology, Owerri, Nigeria. The centre, consisting of a network of eight Apple II microcomputers, is presently used in teaching a second year computer course in Basic and Fortran at the University. This facility, intended to serve until a mainframe computer is acquired, is likely to be expanded to include more microcomputers in the network.

Data acquisition and processing

Data acquisition and processing is yet another area in which reasonably good equipment can be acquired at relatively low cost. If a small number of measurements are to be taken, eg a set of temperatures every ten seconds for a period of about one hour, then the equipment required is relatively simple and much of it available off-the-shelf. For this type of measurement, the author uses a ZX81 with an eight input analog-to-digital (A/D) converter. The A/D converter presently in use was purchased from Thurnall Electronics, Manchester, at about £50.

Where a large number of measurements are to be taken over an extended period of time the above system is not adequate, since additional equipment would be required to control the cassette recorder, the only presently available mass storage unit for the ZX81. The simple system would thus not be suitable for say a data management system for solar or wind energy. The ZX Spectrum is more suited to this purpose, since it can directly control a mass-storage device, such as the ZX microdrive, a disc drive or one of the several high-speed cassette drives. An A/D converter is required for the Spectrum and though this is likely to be available off-the-shelf, the author is currently assembling one. The final cost of this item is not included here, but will be reported at a later date. In fact, a complete data management system, incorporating data acquisition, analysis, reduction and storage is presently under construction. The system is being built around the Spectrum microcomputer and when completed, would be used to monitor solar and wind energy parameters, it is described in more detail in the following paper.

CONCLUSIONS

This paper has attempted to show that some research, though limited in scope, can still be carried out on a small research budget. It also demonstrates that computing facilities need not always be in the form of a large, mainframe computer. The new range of "home" computers, though small and slow by comparison, can still provide adequate facilities at reasonable cost.

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TABLE 1: Estimated cost of small-scale collector system and simulator

Item	**Estimated Cost (£)**
Solarimeter	200
Simulator (Thorn OM1000, CSI Lamp, 1000 W)	250
Circulation pump	6
Flow rate meter	25
Solar collector	15
Miscellaneous (clean plastic tubing, plastic tank, insulation etc.)	5
Total	**511**

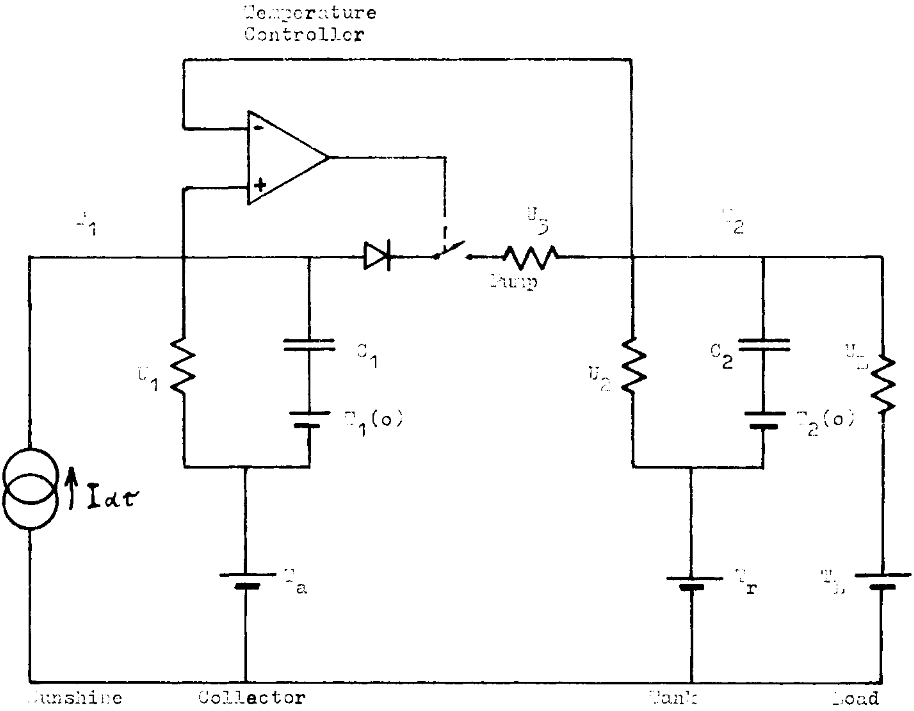

FIGURE 1.
An electrical equivalent circuit of the flat-plate solar water heating system.