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NRCC Air Collector Testing Facility

by M.A. Bernier

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RÉSUMÉ

En 1983, le CNRC a mis sur pied une installation extérieure d'essai des capteurs solaires à air en vue d'améliorer les méthodes et l'équipement d'essai permettant d'évaluer et de mieux caractériser la performance thermique de ces capteurs. L'installation a été étalonnée suivant une méthode globale. À des débits élevés (0,045, 0,080 et 0,160 kg/s), la précision de la mesure du taux d'énergie captée satisfait à la norme ASHRAE 93-77.

NRCC AIR COLLECTOR TESTING FACILITY

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Summary

An outdoor air collector testing facility has been established at NRCC during 1983 to develop improved thermal performance test methods and equipment and better characterizations of air collector thermal performance. The facility was calibrated using an overall calibration approach. At high flow rates (0.045, 0.080 and 0.160 kg/s), accuracy of the measured rate of collected energy, is within the requirements of ASHRAE Standard 93-77.

1. INTRODUCTION

Experimental evaluation of the thermal performance of air solar collectors presents problems related to the experimental procedures and equipment and to the nature of air collectors. An experimental facility capable of performing a complete ASHRAE Standard 93-77 thermal performance test (1), was established at the Division of Building Research. The facility, to be used to evaluate the thermal performance of air collectors and for the development and verification of new measurement techniques and equipment, consists of an altazimuth frame and an air test module (Figure 1).

2.1 THE ALTAZIMUTH FRAME

The altazimuth frame, a welded steel structure mounted on four wheels, supports the collector under test (up to 2.7×2.7 m size) and the air test module. The on-board computer, using the date and time entered by the operator, positions the altazimuth frame so that the face of the collector is perpendicular to the sun's rays (or at a specified angle if an incident angle modifier test is performed) to within $\pm 1^\circ$. A wind vane anemometer and a Precision Spectral Pyranometer (PSP) are attached to the altazimuth frame to measure local wind speed and solar radiation in the plane of the collector. The altazimuth frame rotates on a leveled concrete pad.

2.2 THE AIR TEST MODULE

The air test module (Figure 1) measures mass flow rates before and after the collector using orifice plates according to ASME procedures (2). By selecting one of five orifice plates, collectors can be tested at flow rates up to 0.20 kg/s. Flow through the collector is regulated (to within $\pm 0.6\%$ of the desired value) by bleeding air through a computer-controlled bypass (3).

Inlet and outlet temperatures are measured using both silicon transistors and platinum resistance temperature sensors. To obtain the average temperature and decrease the measurement uncertainty, each type of sensor is connected in series and arranged in an array of five elements (Figure 2). Temperature measurement errors due to radiation exchange

between the sensors and the duct wall are minimized by insulating the temperature measurement section with 20 mm of armaflex insulation and by partially shielding each sensor with a stainless-steel tube. The silicon sensors have a negative temperature coefficient and the platinum ones have a positive coefficient, so that an error due to a drift in the computer's A/D converter can be detected as an apparent divergence of the inlet temperature readings (4). The ambient temperature and the temperature of the air at both orifice plates are measured using five-element platinum resistance temperature sensors. The air temperature at the collector inlet can be controlled within $\pm 0.2^\circ\text{C}$ by a computer-regulated, multi-element strip heater (9.4 kW).

The on-board computer is accessed via a remote terminal. The operator sends a series of commands (3) to the computer and the test is carried out automatically. Data are stored in the on-board computer until the end of the test, when they are transferred via underground cable to a DEC PDP 11/23 computer for analysis and storage.

3.1 CALIBRATION TECHNIQUE AND INSTRUMENTATION

An overall calibration was undertaken to verify the accuracy of the measured rate of collected energy and compare it with the requirements of ASHRAE Standard 93-77. The rate of energy collected by a solar collector with no leakage is defined as:

$$Q_c = \dot{m} \cdot C_p \cdot \Delta T \quad (1)$$

where Q_c = rate of collected energy (W), $\dot{m}$ = mass flow rate (kg/s), C_p = specific heat (J/(kg $\cdot^\circ\text{C}$)) and ΔT = temperature rise across the solar collector ($^\circ\text{C}$).

In the overall calibration approach, the solar collector is replaced with the Calibration Heat Source (CHS) (5), which transfers an accurately measured quantity of electrical energy (P_{in}) to the circulating fluid (air). The accuracy can then be determined by comparing Q_c , as measured by the test loop, with the known input (P_{in}).

In the CHS used (Figure 3), entering air forms a "thermal guard" around the heater. This reduces net heat losses by reducing the temperature difference across the exterior insulation. The heat losses from the CHS are proportional to the difference between air inlet and ambient temperature. To compensate for these losses a correction factor (1.26 W/ $^\circ\text{C}$) must be applied to P_{in} (5).

The power supplied to the CHS is regulated and the power level controlled by a variable transformer. Based on the observed stability of the power input and on the accuracy of the power transducer used for measurements, the accuracy of P_{in} is estimated to be $\pm 0.5\%$. Heat losses from the CHS introduce an additional uncertainty (estimated at $\pm 0.5\%$) in the energy transfer to the circulating fluid.

3.2 CALIBRATION RESULTS

Table I gives the results of a typical calibration test run, performed indoors under steady state conditions. The results, for a flow rate of 0.08 kg/s, are shown on Figure 4, where the accuracy of Q_c is plotted against inlet temperature minus ambient temperature ($T_i - T_a$).

The accuracy of Q_c is defined as: $\left[\frac{P_{in} - Q_c}{P_{in}} \right] \times 100$.

Heat losses in the pipe sections from the temperature measuring locations to the collector (header heat losses) could account for much of the difference between Q_c and P_{in} . The combined header heat losses were

measured by joining the headers end-to-end, and measuring the temperature drop of heated air passing through them. The heat loss coefficient $[(UA)_{HHL}]$ based on the difference between the average fluid temperature $(T_i + T_o)/2$ and the ambient temperature (T_a) was found to be $0.78 \text{ (W/}^\circ\text{C)}$. For well insulated headers of approximately the same size, the header heat losses (Q_{HHL}) are given by: $Q_{HHL} = (UA)_{HHL} [(T_i + T_o)/2 - T_a]$, where $(UA)_{HHL} = 0.78 \text{ (W/}^\circ\text{C)}$ in this case.

The values of Q_c based on the measured T_i and T_o have been corrected for header heat losses and the results superimposed on Figure 4.

The random uncertainty allowed by ASHRAE Standard 93-77 on the measured rate of energy collected was evaluated (Appendix A). No uncertainty was included for header heat losses. All data points lie within the allowable uncertainty intervals, indicated by the vertical bars (Figure 4).

Less extensive calibration tests were performed at four other flow rates (results in Table II). The accuracies of Q_c at 0.160, 0.080, and 0.045 kg/s are acceptable, whereas the accuracies at 0.025 and 0.015 kg/s are outside the uncertainty interval allowed by the Standard. Such problems as incomplete mixing upstream of the temperature sensors, radiation errors, and eccentric location of orifice plates in the pipe, could explain the inaccuracy of Q_c at low flow rates.

4. REFERENCES

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5. APPENDIX A UNCERTAINTY ALLOWED ON Q_c

The random uncertainty allowed by ASHRAE Standard 93-77 on the measured rate of collected energy (Q_c) can be evaluated using the propagation of random measurement uncertainty technique (6). Equation 1 can be expressed in terms of the measured parameters:

$$Q_c = K \cdot C \cdot A \cdot \sqrt{\frac{\Delta P \cdot P_{abs}}{T_{abs}}} \cdot C_p \cdot \Delta T \quad (A-1)$$

where K is a constant, C is the discharge coefficient, A is the area of the orifice, ΔP is the pressure drop across the orifice, P_{abs} is the orifice absolute pressure and T_{abs} is the orifice absolute temperature.

The accuracy requirements of each individual measurement, as given in ASHRAE Standard 93-77, are:

$$W_A = \pm 0.2\%$$

$$W_{P_{abs}} = \pm 2\%$$

$$W_{\Delta T} = \pm 0.1^\circ\text{C}$$

$$W_{\Delta P} = \pm 1\%$$

$$W_{T_{abs}} = \pm 0.5^\circ\text{C}$$

$$W_{C_p} = 0.5\% \text{ (assumed).}$$

The standard does not specify any uncertainty on C : it is assumed to be $\pm 2\%$ (7).

The uncertainty in the dependent variable (W_{Q_c}) can be expressed in terms of the uncertainties in each of the independent variables (W_A , $W_{\Delta P}$, etc) (6). Performing an analysis as described in reference 6, we obtain:

$$\frac{W_{Q_c}}{Q_c} = \left[5.54 \times 10^{-4} + \left(\frac{-0.25}{T_{abs}} \right)^2 + \left(\frac{0.1}{\Delta T} \right)^2 \right]^{\frac{1}{2}}$$

By substituting the corresponding values of T_{abs} and ΔT , values of $\frac{W_{Q_c}}{Q_c}$ are obtained (bars, Figure 4).

TABLE 1 Typical Calibration Results*

ΔT (°C)	$T_i - T_a$ (°C)	P_{in} Corrected for CHS Heat Losses (W)	Q_c (W)	Accuracy of Q_c (%)	Q_{HHL} (W)	Q_c Corrected for HHL (W)	Accuracy of Q_c Corrected for HHL (%)
11.45	31.7	960.1	924	3.8	28.4	952.4	0.8
11.48	31.6	960.2	926	3.6	28.3	954.3	0.6
11.49	31.5	960.3	927	3.5	28.3	955.3	0.5
11.50	31.4	960.4	928	3.4	28.3	956.3	0.4

*Flow rate ($\dot{m}$) = 0.080 kg/s

$P_{in} = 1000 \text{ W}$

Values of $\dot{m}$, ΔT , T_i , T_a were measured at 5-second intervals and averaged over a 5-minute period.

TABLE II Measured and Allowable Accuracy of Q_c
($T_i = T_a$ in all cases)

Upstream Flow Rate (kg/s)	Orifice Plate	P_{in} (W)	Measured ^d ΔT (°C)	Accuracy of Q_c (corrected for HHL) (%)	Allowed random uncertainty ^c (%)
0.160	A	1000	6.0	2.6 ^a	2.9
0.080	B	1000	12.3	0.8 ^a	2.5
0.045	C	1000	21.5	1.9 ^a	2.4
0.025	D	1000	38.2	3.7 ^a	2.4
0.015	E	500	29.2	15.1 ^b	2.4

^a Average of 4 measurements

^b Average of 3 measurements

^c Method described in Appendix A

^d Silicon transistors

FIGURE 1
AIR TEST MODULE (FROM REFERENCE 3)

FIGURE 3
CALIBRATION HEAT SOURCE (FROM WRIGHT AND HOLLANDS)

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FIGURE 2
TEMPERATURE MEASURING SECTION

FIGURE 4
ACCURACY OF Q_c VS $T_i - T_a$ (FLOW RATE 0.08 kg/s)

BR 6510-4

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