Proceedings of the Society for Experimental Biology and Medicine

VOL. 117 | NOVEMBER 1964 | No. 2

SECTION MEETING

SOUTHEASTERN
Academy of Medicine,
Atlanta, Ga.

October 23-24, 1964

A Human Calorimeter.* (29572)

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Human calorimeter studies have been made in the past under static environmental conditions since stabilization time or heat content of thermal barrier materials limit measurement when the environment is changed. Direct calorimetry combined with indirect calorimetry offers the marked advantages of measuring the change in heat content of the body during transient states. Thus the most significant value of direct calorimetry is in dynamic caloric studies where transient energy exchange is measured. The thermal gradient calorimeter as devised by Day and Hardy(1) and Benzinger and Kitzinger(2) permits these studies when the unsteady state is produced by conditioning of the subject at different temperatures prior to insertion into the calorimeter or by increasing heat production by exercise.

The human calorimeter described is designed to indicate variations in body heat exchange and to allow change and stabilization of environment within a few minutes. It is similar in concept to the calorimeter described by Visser and Hodgson(3).

Overall design and performance specifications.† The interior floor space is .91 meter by .76 meter and the height is 1.83 meters allowing the subject to sit or stand in the calorimeter.

Inlet temperature can be regulated at temperatures between 5°C and 50°C. Humidity may be reduced from ambient conditions by a precool coil. The temperature can be changed at a maximum rate of 2.5°C per minute.

Air flow can be changed from .89 Cu meter to 2.67 cubic meter/min. Air flow is measured with a Meriam Flowmeter, model 50

* Aided in part by Grant GM 04829-02 from Nat. Inst. Health and by Contract FA 3086 administered by Federal Aviation Agency.

† Calorimeter designed by Mr. Henry L. Burns, Portland, Oregon. Mr. Wayne Quinton, Seattle, Wash. aided in design and in construction. Calorimeter constructed by United Fabricators, Inc., Seattle, and control system furnished by Minneapolis Honeywell, Seattle.

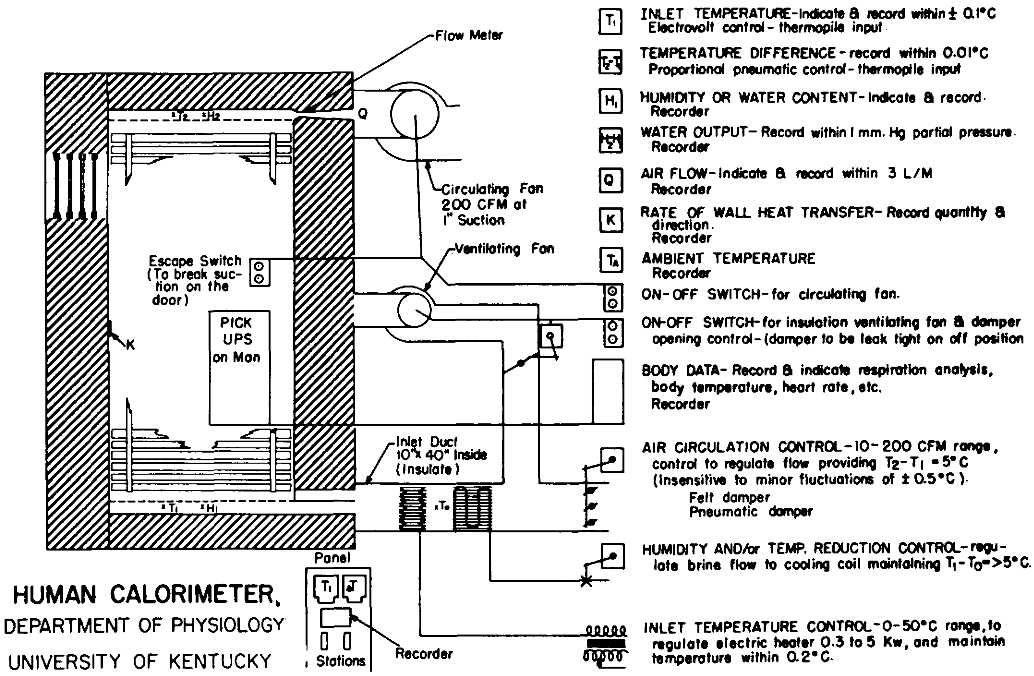

FIG. 1. Sagittal schematic of calorimeter.

MC 2-6 P and a Hastings Precision Air Meter, model B 16 A.

Body heat output is measured as a product of air flow rate and inlet to outlet air temperature difference. Air enters through the floor and exits through the ceiling. The linear rate of flow is 2 to 6 cm/sec.

Heat loss through the calorimeter walls is kept minimal by maintaining an outer room at calorimeter temperature. Heat transfer through the walls and door is measured with Hatfield-Turner discs mounted on the wall (4).

Perspired and respired moisture are measured as a humidity change in the air stream

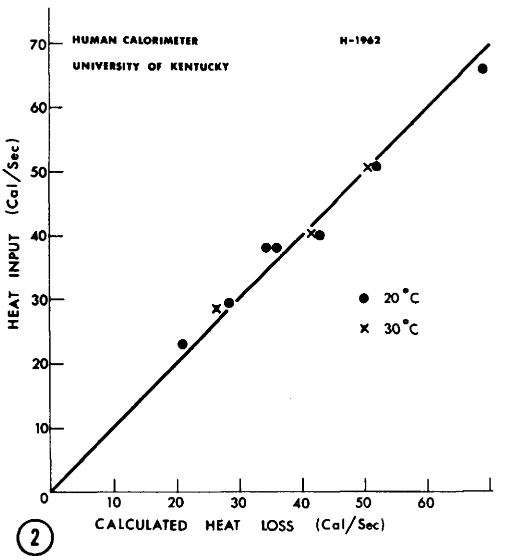

FIG. 2. Heat input plotted against calculated heat loss at 20°C and 30°C.

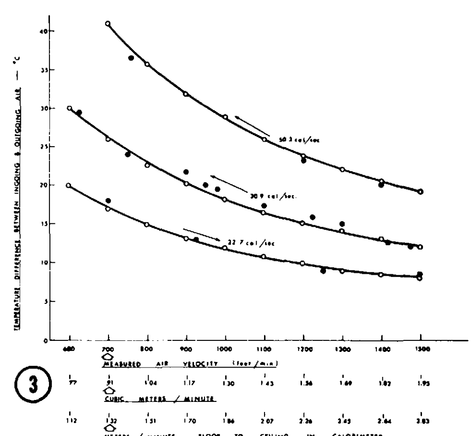

FIG. 3. Measured temperature difference at 3 heat inputs with various air flows. Lines represent theoretical value.

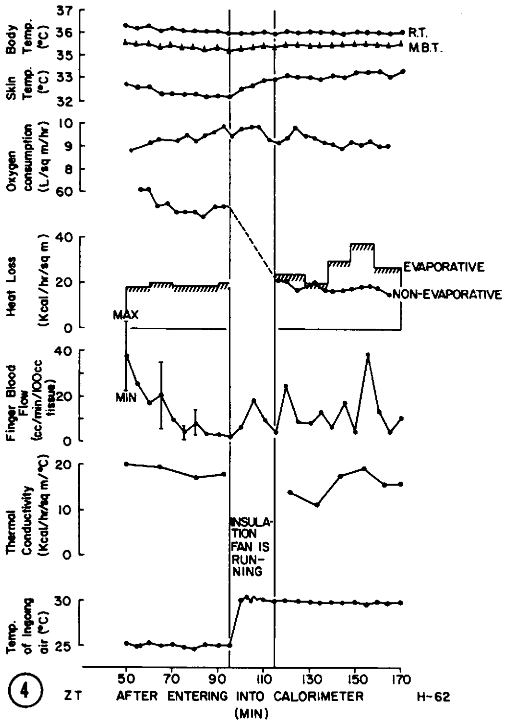

FIG. 4. Ordinate, values measured during a calorimeter experiment in time (abscissa). Air temperature was changed after 95 min.

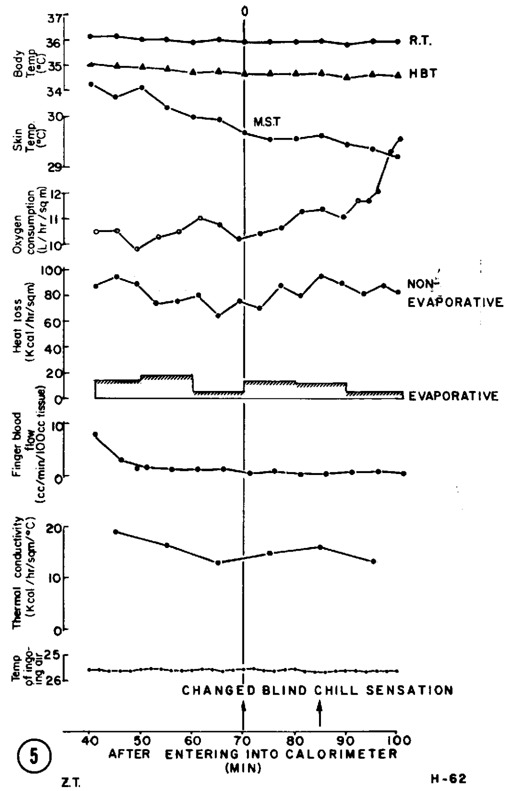

FIG. 5. Ordinate, values measured during a calorimeter experiment in time (abscissa). The blind was changed from reflecting to absorbing at 70 min.

(Hygrodynamics wide range sensing elements).

Indirect calorimetry is accomplished with a pneumotachograph and integrating flowmeter. Gas samples are continuously drawn and analyzed for O_2 with a Beckman model F-3 analyzer and for CO_2 with a Beckman model LB-1 CO_2 analyzer.

Skin temperatures are monitored by thermistors manufactured by the Yellow Springs Instrument Co.

Essential features of the calorimeter are shown in Fig. 1 in a sagittal schematic. The insulation is a porous foamed plastic through which air can be passed when temperature is changed. In this way most of the thermal lag is removed. When the subject is seated in the calorimeter a set of venetian blinds, polished aluminum on one side and black on the other, may be used to change the amount of radiation.

Calibration. The calorimeter has been calibrated with an electric heater and with an alcohol lamp. The relation between heat input and calculated output is shown in Fig. 2 with measurements at 2 different calorimeter temperatures. The temperature difference between inlet and outlet air at various air speeds and heat input are shown related to theoretical values in Fig. 3. A blind test of the humidity sensing elements is shown in Table I.

Preliminary tests in calorimeter. Preliminary tests were conducted on 3 subjects at temperatures between 15°C and 38°C to

TABLE I. Blind Test of Hygrometer.
(At measured air velocity of 1500 f/min.)

Calorimeter temperature (°C)	Water content (g/l) of Ingoing air	Water content (g/l) of Outgoing air	Error (g/l)
20	.0087786	.0087988	.0000202
25	.0095549	.0096302	.0000753
30	.0115395	.0115654	.0000259

TABLE II. Calorimeter Data and Calculations.

Ambient temp (°C)	Rectal temp (°C)	Mean body temp (°C)	Mean skin temp (°C)	Oxygen consumption ($l/m^2/hr$)	Heat loss ($cal/m^2/hr$) Non-evap	Evap	Total	Thermal conductance ($cal/m^2/hr/°C$)	Finger blood flow (cc/min/100 cc)	Finger temp (°C)	Thermal circulation index Total body†	Finger‡
				Subject, W.V.J.—24 yr—height 173 cm—weight 77.9 kg								
14.8*	36.1	34.1	26.0	11.18	99.97	22.77	122.74	12.1	1.0	25.6	1.1	1.0
19.8	36.2	34.7	28.6	9.41	71.85	7.72	79.57	10.5	1.9	27.5	1.2	.9
	36.0	34.4	28.0	9.99	65.17	8.22	73.39	9.2	.5	26.6	1.0	.7
24.2	36.2	35.2	31.2	10.94	46.75	17.51	64.26	12.8				
	36.1	34.8	30.9	10.58	37.49	17.51	55.00	10.6	18.9	32.7	1.3	2.5
25.0	36.7	36.0	33.2	9.34	42.76	16.52	59.28	16.9	44.6	35.0	2.3	5.9
	36.2	35.6	32.9	9.67	30.00	22.17	52.17	15.8	34.6	34.3	2.4	4.9
29.2	36.2	35.5	33.0	9.19	22.35	24.17	46.52	14.5	26.5	34.9	1.2	4.4
	36.2	35.6	33.1	9.32	24.62	24.80	49.42	15.9	30.0	34.5	1.3	3.1
31.0	36.5	36.0	34.0	9.16	17.08	23.67	40.75	16.3	40.8	35.5	1.2	4.5
	36.5	36.1	34.3	9.24	24.18	25.50	49.68	22.6	28.3	35.4	1.5	4.0
35.2	36.6	36.5	35.2	8.80	1.32	40.90	42.22	30.1	37.1	35.9	1.0	1.0
	36.8	36.5	35.2	9.22	3.65	41.13	44.78	27.9	34.3	35.8		.6
38.0	37.0	36.7	35.7	9.32	−15.82	66.52	50.70	39.0			−1.8	
	37.0	36.7	35.5	9.28	−19.53	72.01	52.48	35.0			−1.7	
				Subject, Z.A.T.—25 yr—height 166.8 cm—weight 56.8 kg								
20	35.8	34.1	27.4	14.52	76.43	15.28	91.71	10.9	1.1	29.2	.9	1.4
23.8	36.0	35.0	30.7	11.33	60.16	6.50	66.66	13.1	3.5	30.5	1.3	1.2
	35.9	34.7	30.1	11.89	54.48	4.94	59.42	10.2	.8	27.2	1.1	.4
26.0	36.4	35.5	32.0	9.59	59.20	19.07	78.27	17.8	19.0	33.6	1.4	2.7
	36.2	35.0	31.0	9.63	58.50	21.60	80.10	15.4	8.8	33.0	1.0	2.2
27.3	36.2	35.4	32.3	9.26	39.06	19.60	58.66	15.0	9.3	34.3	1.3	3.7
	36.0	35.2	31.9	10.56	37.76	22.89	60.65	14.6	3.0	32.0	1.1	1.2
29.0	36.4	35.9	33.6	9.51	33.06	30.00	63.06	22.5	41.8	35.5	1.6	7.2
	36.2	35.6	33.2	9.87	26.30	28.80	55.10	18.4	27.3	35.0	1.4	5.0
30.5	36.4	36.0	34.5	10.43	25.60	25.64	51.24	26.9	30.9	35.8	2.1	8.8
34.0	36.9	36.6	35.3	8.82	5.26	43.23	48.49	30.3	35.2	35.3	.8	.8
	37.0	36.6	35.3	9.05	4.67	48.03	52.70	31.0	43.8	35.4	.8	.9
36.0	36.4	36.2	35.7	9.48	−12.20	77.55	65.35	93.3		36.2	−.4	1.0
	36.6	36.4	35.5	10.23	−10.94	77.91	66.97	60.9	47.9	36.2	−.5	.5
				Subject, K.C.—17 yr—height 175 cm—weight 73.5 kg								
20.0	36.3	34.8	28.3	10.49	81.06	16.22	97.28	12.16	8.5	31.0	1.0	2.1
	36.0	34.4	27.7	11.46	75.02	12.93	87.95	10.60	1.4	28.1	.9	1.0
23.5	36.4	35.3	30.6	10.22	65.63	3.98	69.61	12.00	9.1	32.4	1.2	2.2
	36.2	35.0	29.9	11.11	58.32	11.30	69.62	11.05	2.6	32.0	1.0	2.0

TABLE II. Continued.

Ambient temp (°C)	Rectal temp (°C)	Mean body temp (°C)	Mean skin temp (°C)	Oxygen consumption (l/m²/hr)	Heat loss (cal/m²/hr) Non-evap	Evap	Total	Thermal conductance (cal/m²/hr/°C)	Finger blood flow (cc/min/100 cc)	Finger temp (°C)	Thermal circulation index Total body†	Finger‡
25.0	36.5	35.5	31.8	9.86	47.80	19.88	67.68	14.4	23.1	34.2	1.4	4.0
	36.2	35.3	31.5	10.17	49.82	21.22	71.04	15.1	10.6	32.9	1.4	2.4
27.3	36.7	36.0	32.2		42.44	15.92	58.36	13.0	71.4	35.0	1.1	4.5
	36.4	35.8	32.1	9.40	39.90	20.52	60.42	14.0	56.1	34.8	1.1	4.7
30.0	36.9	36.2	33.6	9.48	19.43	23.68	43.11	13.1	32.2	35.8	1.1	5.3
	36.9	36.3	33.9	9.88	26.27	30.48	56.75	18.9	51.0	35.6	1.3	4.3
34.5	36.8	36.5	35.4		4.02	30.90	34.92	24.9	86.1	36.1	.6	2.3
	36.8	36.6	35.7	9.36	.96	40.18	41.14	37.4	87.0	36.1	1.1	2.3
35.5	36.5	36.4	35.8	9.57	2.50	51.90	54.40	77.7	51.0	36.2	.4	2.3

* 1. The first one hour after beginning the measurement. 2. The second one hour.

† Calculated by $\frac{\text{M.S.T.} - \text{Ambient temp}}{\text{Rect temp} - \text{M.S.T.}}$.

‡ Calculated by $\frac{\text{Finger temp} - \text{Ambient temp}}{\text{Rect temp} - \text{Finger temp}}$.

Condition: After staying in a room controlled at 25°C without breakfast, the subject was kept in a calorimeter chamber under nude condition and in sitting position. The measurement was begun one hr after keeping subject in calorimeter.

establish the consistency of the data provided from this instrument with that from other measures. The data are compiled in Table II.

In addition studies were made with 3 step changes in the calorimeter environment. A change from 25°C to 30°C illustrates the reduction in non-evaporative loss with the increase in evaporative loss, Fig. 4. A calculated conductivity of air is 0.144 Kcal/°CM^2 hr and 0.167 Kcal/°CM^2 hr at 25°C and 30°C. Blood flow and calculated body conductivity show little change.

In Fig. 5 the influence of increasing radiant loss is illustrated. An increase in oxygen consumption without change in air temperature is apparent. In this case the calculated insulation of air is higher due to reduced air flow.

Discussion. This design of calorimeter allows studies of heat exchange over a range of temperatures from 5°C to 40°C and offers the opportunity to make step changes in certain avenues of heat loss. The dependence on air temperature, air velocity and air humidity measurements makes operational accuracy a constant problem.

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Received June 4, 1964. P.S.E.B.M., 1964, v117.