Appendix: Calculation example

Assume a trained cyclist with the following general characteristics: a gross mechanical efficiency (**GE**) on the bike of 20%, a body height of 175.0 cm, a body mass of 72.0 kg and a core temperature in rest of 37.0 °C. This results in a body surface area (**A_D**) of 1.8694 m^2 and in a body heat capacity constant (**BHC**) of 133754.7 J/°C. The (indoor) environment is warm but has an average humidity, relative humidity of 50% and the ambient temperature is 30 °C. The cyclist is doing a steady-state workout at constant cycling power output (**PO**) of 200 Watt and we assume in our example that the core temperature increases (despite heat exchange with the environment) with 0.05 Celsius every minute, because of an imbalance between heat gain and heat loss! After 11 minutes the core temperature has reached a level of 37.55 °C.

During the example workout the following environmental values relevant to the Heat-Balance-Equation can be determined:

Time (Min.)	Tcore (C)	Tbody (C)	Psk (kPa)	Pair (kPa)	DPska (kPa)	Tskin (C)	Tair (C)	DTska (C)
1.00	37.05	36.33	5.59	2.12	3.47	34.88	30.00	4.88
2.00	37.10	36.36	5.58	2.12	3.46	34.85	30.00	4.85
3.00	37.15	36.39	5.58	2.12	3.45	34.84	30.00	4.84
4.00	37.20	36.42	5.57	2.12	3.45	34.83	30.00	4.83
5.00	37.25	36.45	5.57	2.12	3.44	34.82	30.00	4.82
6.00	37.30	36.48	5.56	2.12	3.44	34.80	30.00	4.80
7.00	37.35	36.50	5.56	2.12	3.44	34.79	30.00	4.79
8.00	37.40	36.53	5.55	2.12	3.43	34.77	30.00	4.77
9.00	37.45	36.56	5.55	2.12	3.43	34.75	30.00	4.75
10.00	37.50	36.59	5.54	2.12	3.42	34.74	30.00	4.74
11.00	37.55	36.62	5.54	2.12	3.42	34.72	30.00	4.72

Notice that the mean body temperature gains less in temperature than the internal core body temperature due to a lowering of the mean skin temperature because of an increasing air flow that cools the skin!

When pushing constantly 200 Watt power output (**PO**), the **W_{ext}** is calculated as **PO/A_D** = 200/1.8694 = 107 (J/m2). Consequently the Metabolic free energy production (**M**) during the workout can be calculated with the formula: **PO***(100/**GE**)/**A_D** (J/m^2) . The result in time is shown in the table**.**

Time (Min.)	Wext (J/m2)	M (J/m2)	SumM (kJ/m2)	SumM (kJ)	SumM (kcal)
1.00	107.00	535.00	32.00	60.00	14.00
2.00	107.00	535.00	64.00	120.00	29.00
3.00	107.00	535.00	96.00	180.00	43.00
4.00	107.00	535.00	128.00	240.00	57.00
5.00	107.00	535.00	160.00	300.00	72.00
6.00	107.00	535.00	193.00	360.00	86.00
7.00	107.00	535.00	225.00	420.00	100.00
8.00	107.00	535.00	257.00	480.00	115.00
9.00	107.00	535.00	289.00	540.00	129.00
10.00	107.00	535.00	321.00	600.00	143.00
11.00	107.00	535.00	353.00	660.00	158.00

The total Metabolic energy production (**SumM**) during a minute (60 seconds) of exercise can be determined by **M***60/1000 (kJ/m2) or when this is multiplied with A_D in kJ or multiplied with A_D/4.1868 in kcal.

Internal Heat production (**H**) is calculated with the formula: **PO***((100/**GE**) **- 1**)/A_D (J/m^2) and the results during exercise are shown in the following table.

Time (Min.)	H (J/m2)	SumH (kJ/m2)	SumH (kJ)	SumH (kcal)
1.00	428.00	26.00	48.00	11.00
2.00	428.00	51.00	96.00	23.00
3.00	428.00	77.00	144.00	34.00
4.00	428.00	103.00	192.00	46.00
5.00	428.00	128.00	240.00	57.00
6.00	428.00	154.00	288.00	69.00
7.00	428.00	180.00	336.00	80.00
8.00	428.00	205.00	384.00	92.00
9.00	428.00	231.00	432.00	103.00
10.00	428.00	257.00	480.00	115.00
11.00	428.00	282.00	528.00	126.00

The total Internal heat production (**SumH**) during a minute (60 seconds) of exercise can be determined by **H***60/1000 (kJ/m2) or when this is multiplied with A_D in kJ or multiplied with A_D/4.1868 in kcal.

Mean body temperature increases in our example at an average rate of about 0.03 °C per 60 seconds. So, every minute an equivalent of Heat is stored internally in the body that causes the rise in body temperature. The internally Stored Heat (**S**) is the sum of the heat stored (**DeltaS**), measured at every minute during the workout. **DeltaS** is calculated every minute with the formula: **BHC***(DeltaTbody)/60. DeltaTbody is the temperature increase/decrease during that minute of the workout! Internal stored heat is shown in the following table:

Time (Min.)	S (J/m2)	DeltaS (J/m2)
1.00	94.00	93.50
2.00	143.00	49.80
3.00	215.00	71.80
4.00	278.00	62.50
5.00	343.00	65.50
6.00	407.00	63.70
7.00	471.00	63.90
8.00	534.00	63.30
9.00	597.00	63.00
10.00	660.00	62.60
11.00	722.00	62.30

Heat exchange by Radiation (**R**) can be determined and is shown during the workout in the following table:

Time (Min.)	R (J/m2)
1.00	22.90
2.00	22.80
3.00	22.80
4.00	22.70
5.00	22.60
6.00	22.60
7.00	22.50
8.00	22.40
9.00	22.30
10.00	22.30
11.00	22.20

All terms of the Heat Balance equation are determined and consequently the requested airflow velocity can be calculated to maximize heat exchange with the environment.

$$V_a = ((H + S - R) / (H_c * \Delta T_{ska} + H_e * \Delta P_{ska}))^{1.1904}$$

In the following table, where **F2** = **($H_c * \Delta T_{ska}$ + $H_e * \Delta P_{ska}$)**, the requested Air Flow Velocity (**Va**) is calculated for every step in the workout.

Time (Min.)	H (J/m2)	R (J/m2)	S (J/m2)	H+S-R	F2	(H+S-R)/F2	Va (m/s)	Va (km/h)	C (J/m2)	Ereq (J/m2)	SwRate (g/m2/h)
1.00	428.00	22.90	94.00	499.10	527.50	0.95	0.94	3.37	39.20	459.30	448.80
2.00	428.00	22.80	143.00	548.20	525.70	1.04	1.05	3.79	43.00	505.50	479.10
3.00	428.00	22.80	215.00	620.20	525.50	1.18	1.22	4.39	48.60	571.70	522.60
4.00	428.00	22.70	278.00	683.30	524.70	1.30	1.37	4.93	53.40	629.50	560.60
5.00	428.00	22.60	343.00	748.40	524.00	1.43	1.53	5.50	58.50	690.10	600.40
6.00	428.00	22.60	407.00	812.40	523.20	1.55	1.69	6.08	63.40	749.00	639.10
7.00	428.00	22.50	471.00	876.50	522.50	1.68	1.85	6.66	68.20	808.10	677.90
8.00	428.00	22.40	534.00	939.60	521.70	1.80	2.01	7.25	73.00	866.70	716.40
9.00	428.00	22.30	597.00	1002.70	520.90	1.93	2.18	7.85	77.80	925.00	754.70
10.00	428.00	22.30	660.00	1065.70	520.00	2.05	2.35	8.46	82.50	983.00	792.80
11.00	428.00	22.20	722.00	1127.80	519.20	2.17	2.52	9.07	87.20	1040.70	830.70

When the requested Air Flow Velocity is known the other heat exchange terms (**C**onvection and **E**vaporation) can be calculated separately. Notice that **C + E = H + S - R** for all steps in the workout.