# Ergonomics of the thermal environment
# Determination of metabolic rate

**This document of which I was the main writer (Prof J. Malchaire) became the international standard 8996. Since I was never remunerated for this work and that I yielded the royalties to nobody, I consider that I have the right to diffuse it the document which been used as a basis for the edition of the standard ISO 8996.**

**The program** *Malchaire_interpretation_charge _travail_FC.exe* **available via my repertory DROPBOX follows the procedure of level 3, Analyze.**

## Contenu

# 1 Scope

The metabolic rate, as a conversion of chemical into mechanical and thermal energy, measures the energetic cost of muscular load and gives a quantitative estimate of the activity. Metabolic rate is an important determinant of the comfort or the strain resulting from exposure to a thermal environment. In particular, in hot climates, the high levels of metabolic heat production associated with muscular work aggravate heat stress, as large amounts of heat need to be dissipated, mostly by sweat evaporation. On the contrary, in cold environments, high levels of metabolic heat production help to compensate for excessive heat losses through the skin and therefore reduce the cold strain.

This International Standard specifies different methods for the evaluation of metabolic rate in the context of ergonomics of the thermal working environment. It can also be used for other applications — for example, the assessment of working practices, energetic cost of specific jobs or sport activities, the total energy cost of an activity, etc.

The estimations, tables and other data included in this International Standard concern the general working population. Users should make appropriate corrections when they are dealing with special populations including children, aged persons, people with physical disabilities, etc. Personal characteristics, e.g. body mass, may be used if the body is moved due to walking or climbing (Annex A and B). Gender, age and body mass are considered in Annex C for the evaluation of the metabolic rate from heart rate.

# 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9886, *Ergonomics of the thermal environment — Evaluation of thermal strain by physiological measurements*

ISO 13731, *Ergonomics of the thermal environment — Vocabulary and symbols*

ISO 15265, *Ergonomics of the thermal environment — Risk assessment strategy for the prevention of stress or discomfort in thermal working conditions*

# 3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

# 4 The units

The metabolic rate associated with a given task and estimated using the methods described in this document shall be expressed in watts.

If the task does not involve displacements, the metabolic rate will not vary as a function of the size and the weight of the person. If it involves displacements, then the weight of the person must be taken into account (see Annex B).

As the heat associated to this metabolic rate and produced inside the body must leave it essentially through the skin, thermophysiologists usually express the metabolic rate per unit of body surface area (in $W \cdot m^{-2}$) and the estimations of thermal comfort and thermal constraints described in other standards of this series are always done using metabolic rates in $W \cdot m^{-2}$.

# 5 The 4 levels of methods for estimating the metabolic rate

The mechanical efficiency of muscular work — called the 'useful work' — is low. In most types of industrial work, it is so small (a few percent) that it is assumed to be nil. This means that the energy spent while working is assumed to be completely transformed into heat. For the purposes of this International Standard, the metabolic rate is assumed to be equal to the rate of heat production.

Table 1 lists the different approaches presented in this International Standard for determining the metabolic rate.

These approaches are structured following the philosophy exposed in ISO 15265 regarding the assessment of exposure. Four levels are considered:

— Level 1, *Screening*: a method simple and easy to use is presented to quickly classify as light, moderate, high or very high the mean workload according to the kind of activity.

— Level 2, *Observation*: a time and motion study is presented for people with full knowledge of the working conditions but without necessarily a training in ergonomics, to characterize, on average, a working situation at a specific time:

A procedure is described to successively record the activities with time, estimate the metabolic rate of each activity using formulas and data presented in Annex B and compute the time weighted average metabolic rate.

— Level 3, *Analysis*: one method is addressed to people trained in occupational health and ergonomics of the thermal environment. The metabolic rate is evaluated from heart rate recordings over a representative period. This method for the indirect evaluation of metabolic rate is based on the relationship between oxygen uptake and heart rate under defined conditions. Another method at this level is based on the use of accelerometry to record body movement.

— Level 4, *Expertise*: 3 methods are presented. They require very specific measurements made by experts:

- Method 4A: the oxygen consumption measured over short periods (10 min to 20 min);
- Method 4B: the so-called doubly labelled water method aiming at characterizing the average metabolic rate over much longer periods (1 to 2 weeks);
- Method 4C: a direct calorimetry method.

**Table 1 — Levels for the evaluation of the metabolic rate**

| Level | Method | Accuracy | Inspection of the work place |
|---|---|---|---|
| **1 Screening** | Classification according to activity | Rough information Very great risk of error | Not required |
| **2 Observation** | Time and motion study | High error risk<br>Accuracy: ±20 % | Required |
| **3 Analysis** | 3A: Heart rate measurement under defined conditions | Medium error risk<br>Accuracy: ±10 % | Study required to determine a representative period |
| | 3B: Accelerometry | High risk of error | |
| **4 Expertise** | 4A: Measurement of oxygen consumption | Errors within the limits of the accuracy of the measurement or of the time and motion study, if assumptions (10.1.1, 10.1.4) are met<br>Accuracy: ±5 % | Time and motion study necessary |
| | 4B: Doubly labelled water method | | Inspection of work place not required, but leisure activities must be evaluated. |
| | 4C: Direct calorimetry | Errors within the limits of the accuracy of the measurement or of the time and motion study<br>Accuracy: ±5 % | Inspection of work place not required. |

The accuracy of each method is provided in Table 1 as coefficient of variation (CV), i.e. the percentage ratio of the standard deviation to the mean, and should be understood as indicative values, which might increase due to non-controlled influences discussed below. The accuracy increases from level 1 to level 4 and, as far as possible, the most accurate method should be used.

Attention must be drawn to various sources of variations:

- For a person trained in the activity, the variation is about 5 % under laboratory conditions;
- Under field conditions, i.e. when the activity to be measured is not exactly the same from test to test, a variation of up to 20 % can be expected;
- In cold conditions, an increase of up to 400 W may be observed when shivering occurs.
- Heavy clothing might also increase the metabolic rate by 20% or more, by increasing the weight carried by the person and decreasing the person's ease of movement.

Attention must be drawn to the fact that the accuracy depends also upon:

- The representativeness of the time period observed
- The possible disturbance of the normal activity by the observer and/or the procedure. In this regard, the method based on heart rate recordings appears to be one that interferes the least with the activity.
- the number of measurements: repetition is one method to reduce random measurement error. Based on the CV of an unbiased estimate, the formula (actual CV / requested CV)2

approximates the required number of repetitions. This implies that in order to achieve the 10% accuracy level, two measurements would be necessary with a method actually providing 14%, while four repetitions would be needed with 20% accuracy, and even 9 with 30%. Of course, this improvement only will work if no systematic errors are made.

# 6 Level 1, Screening: Classification of metabolic rate by categories

The metabolic rate can be estimated approximately using the classification given in Annex A. Table A.1 defines five classes of metabolic rate: resting, low, moderate, high, very high. For each class, a range of metabolic rate values is given as well as a number of examples. These activities are supposed to include short rest pauses. An inspection of the work place is not necessary.

The examples given in Table A.1 illustrate the classification.

The method provides only a rough estimate of the metabolic rate and there are considerable possibilities for error. As the accuracy is low, this method should only be used for classification purposes without interpolation between the 4 levels.

# 7 Level 2, Observation: Time and motion study

## 7.1 Evaluation of metabolic rate for a given activity

Annex B gives mean values or formulas for estimating the metabolic rate in watts in the following cases:

- At rest;
- When walking with/without load at < 6 $km \cdot h^{-1}$;
- When running with/without load at ≥ 6 $km \cdot h^{-1}$;
- When going up or down stairs and ladders;
- When lifting or lowering loads without displacement;
- For activities without displacement, from the observation of the body segment involved in the work: both hands, one arm, two arms, the entire body;
- Taking into account the body posture: sitting, kneeling, crouching, standing, standing stooped;

## 7.2 Evaluation of the mean metabolic rate over a given period of time

To evaluate the average metabolic rate over a given period of time, it is necessary to carry out a detailed study of the work. This involves:

- Determining the list of activities performed during this period of time;
- Estimating the metabolic rate for each of these activities taking account of their characteristics and using the data in Annex B: speed of displacement, heights climbed, weights manipulated, number of actions carried out, etc.;
- Determining the time spent at each activity over the whole period of time considered.

The time weighted average metabolic rate for the time period can then be evaluated using the equation:

$$M = \frac{1}{T}\sum_{i=1}^{n} M_i t_i \quad (1)$$

where

$M$ is the average metabolic rate for the work cycle, W;

$M_i$ is the metabolic rate for activity $i$, W;

$t_i$ is the duration of activity $i$, min;

$T$ is the total duration, min, of the period of time considered, and is equal to the sum of the partial durations $t_i$.

The procedure of this time and activity evaluation is further described in Annex B.

## 7.3 Accuracy

The accuracy of the time and motion study depends upon the accuracy of the formulas used (see annex B), but mostly upon the level of training of the observer and his/her knowledge of the working conditions: the possibility for errors is high

# 8 Level 3, Analysis

## 8.1 Evaluation of metabolic rate using heart rate

### 8.1.1 Principle of the method

In the case of pure dynamic work using major muscle groups, with no static muscular, thermal and mental loads, the metabolic rate may be estimated by measuring the heart rate while working. Under such conditions, a linear relationship exists between the metabolic rate and the heart rate. If the above mentioned restrictions are taken into account, this method can be more accurate than the level 1 and level 2 methods of evaluation (see Table 1) and is considerably less complex than the methods listed at level 4.

In that case, the relationship between heart rate and metabolic rate can be written as:

$$M = a + b \, \mathrm{HR} \quad (2)$$

where

- $M$ is the metabolic rate, W;
- HR is the heart rate measured, beats·min$^{-1}$;
- $a$ and $b$ are coefficients

The heart rate may be recorded continuously, for example by the use of telemetric equipment, or, with a reduction in accuracy, measured manually by counting the arterial pulse rate.

The mean heart rate may be computed over fixed time intervals, for example 1 min, over a given period of time or over the whole shift time.

The accuracy of this estimation of the metabolic rate depends upon:

— The accuracy and validity of the relation (2)

— The magnitude of the HR components not linked to the dynamic muscular load

### 8.1.2 Determination of the (HR-M) relationship for purely dynamic muscular work

The relationship between heart rate and metabolic rate can be determined by different methods of decreasing accuracy:

- The most accurate method consists of recording the heart rate and corresponding oxygen consumption at different effort levels during a cardiac stress test on an ergometer or a treadmill in "neutral" conditions, that is, in an environment that will not increase core temperature. The (HR – M) can be used provided the durations of the efforts at each level are such that stable HR and oxygen consumption values are reached.

  Studies showed that the MWC during manual crank efforts was 23% to 30% lower than that measured for the same HR value during a cardiac stress test on bicycle or treadmill. Using the (HR-M) relation results derived from tests on ergometer or treadmill will therefore lead in these cases to an overestimation of the real energy expenditure.

  This method of determination of the (HR – M) relationship is very strenuous and is usually performed in a medical environment.

- A simpler procedure consists of recording the stable heart rate during a few dynamic efforts whose metabolic rates are known. The step-test method is an example of such a procedure, as well as the use of the Astrand-Rythming nomogram.The accuracy is then reduced as the oxygen consumption is not measured.

- When the above methods cannot be used, the (HR – M) relationship can be derived from estimations of the following parameters

  — the heart rate at rest under neutral thermal conditions, $\mathrm{HR}_0$, beats·min$^{-1}$;

  — the metabolic rate at rest, $M_0$, W;

  — the maximum working capacity, MWC, W;

  — the maximum heart rate $\mathrm{HR}_{max}$, beats·min$^{-1}$;

  — the computation of increase in heart rate per unit of metabolic rate:

  $$\mathrm{RM} = (\mathrm{HR}_{max} - \mathrm{HR}_0)/(\mathrm{MWC} - M_0)$$

  The (HR-M) relation is then given by:

$$M = M_0 + (\mathrm{HR} - \mathrm{HR}_0) / \mathrm{RM} \quad (3)$$

The accuracy of this relation is a function of the validity of the estimations of HR0, M0, HRmax and MWC. Annex C proposes formulas for estimating these 4 parameters as a function of the sex, age, lean weight and height on a person of "average" fitness. Taking into account the uncertainty of the estimations of the 4 parameters, the accuracy of the method in annex C is estimated to be 10 to 15%. It must be underlined that this accuracy is for purely dynamic work exerted essentially with the lower limbs and for a mean-fit person. The error is likely to be greater by excess for an unfit sedentary person and by default for a fit sporty person.

- An even simpler method is to use direct evaluations of the (HR-M) relationship such as provided in Table C.1 provides direct evaluations of the (HR − *M*) relationship for women and men with ages ranging from 20 years to 65 years and body masses ranging from 50 kg to 110 kg. The precision is then further reduced.

### 8.1.3 Evaluation of the metabolic rate as a function of HR in real situation

In any given situation, the heart rate at a given time may be regarded as the sum of several components:

$$HR = HR_0 + \Delta HR_M + \Delta HR_S + \Delta HR_T + \Delta HR_N + \Delta HR_\varepsilon \quad (4)$$

where

$HR_0$ is the heart rate, in beats per minute, at rest under neutral thermal conditions;

$\Delta HR_M$ is the increase in heart rate, in beats per minute, due to dynamic muscular load, under neutral thermal conditions;

$\Delta HR_S$ is the increase in heart rate, in beats per minute, due to static muscular work (this component depends on the relationship between the force used and the maximum voluntary force of the working muscle group);

$\Delta HR_T$ is the increase in heart rate, in beats per minute, due to heat stress;

$\Delta HR_N$ is the increase in heart rate, in beats per minute, due to mental load;

$\Delta HR_\varepsilon$ is the change in heart rate, in beats per minute, due to other factors, for example respiratory effects, circadian rhythms, dehydration.

The model of prediction of M from HR described in annex C mentions an accuracy of 10 to 15%. This can only be obtained if the HR recording is made on an "averagely fit" person and in the case of a purely dynamic work in a neutral environment.

When these evaluations made using this model are compared with data recorded in the field, differences will usually be observed due to the factors listed in section 5 and the following factors.

The fact that the subjects are not "averagely fit": to reduce this error, a correction may be applied as a function of the fitness of the person as follows:

a. For unfit people (having no physical activity at work or in their leisure time): MWC = MWC * 0.75

b. For fit people (having everyday vigorous-intensity activity): MWC = MWC * 1.25

- The fact that the work is performed in a hot environment that can lead to a significant increase of HR: the error on the evaluation of M might then rise dramatically and the accuracy level might fall behind level 2 methods.
  To eliminate or, at least reduce the resulting error, the HR recordings should be made in a neutral environment, that is, in thermal conditions in which the core temperature does not increase and these thermal HR components do not exist. If it is not possible, it is mandatory to correct the heart rate measurements for thermal effects by the procedure described in Annex E.
- The fact that the work performed by the subject is not purely dynamic and that the HR components due to static work, stress, mental load, etc. might be important. As these components may not be evaluated and subtracted, the estimated M value will be an overestimation of the true energy expenditure. In a cold environment, this overestimation will result in an underestimation of the risk for the people exposed, while, in the case of heat stress (even after the mandatory correction for the heat component of HR) it will lead to a prediction of a greater risk and therefore result in an increased protection of the people.

In any case, the HR values, including all the possible components, as well as the metabolic rates estimated from them, reflect the global strain of the person and therefore can be used to estimate the strenuousness of the task or job.

# Annex A
## Evaluation of the metabolic rate at level 1, *Screening*

This annex provides the data to classify simply and easily the mean workload for different activities for level 1, *Screening*:

**Table A.1 — Classification of metabolic rate by category**

| Class | Range of metabolic rates W | Examples |
|---|---|---|
| 0 Resting | 100 to 125 | Resting, sitting at ease |
| 1 Low metabolic rate | 125 to 235 | Sedentary activity (office, dwelling, school, laboratory: writing, typing, drawing, sewing, book keeping);<br>Standing, light activity (shopping, laboratory, light industry);<br>Hand and arm work (small bench tools, inspection, assembly or sorting of light materials);<br>Light arm and leg work (driving vehicle in normal conditions, operating foot switch or pedal);<br>Machining with low power tools (drilling (small parts), milling (small parts), coil winding, sawing);<br>Casual walking (2 $km \cdot h^{-1}$) on the level, even path, solid with load ≤ 30 kg. |
| 2 Moderate metabolic rate | 235 to 360 | Sustained hand and arm work (hammering in nails, filing, loading, polishing);<br>Arm and leg work (off-road operation of lorries, tractors or construction equipment);<br>Arm and trunk work (work with pneumatic hammer, tractor assembly, plastering);<br>Weeding, hoeing, picking fruits or vegetables;<br>Pushing or pulling lightweight carts or wheelbarrows;<br>Brick-laying, 5 bricks/min;<br>Intermittent handling of moderately heavy material;<br>Walking (2,5 to 5 $km \cdot h^{-1}$) on the level, even path, solid with load ≤ 20 kg;<br>Walking (2,5 to 3 $km \cdot h^{-1}$) on levelled but irregular - unstable ground with load ≤ 20 kg;<br>Walking (≤ 2.5 $km \cdot h^{-1}$) on stable ground uphill (≤ 5 %) with load ≤ 20 kg. |
| 3 High metabolic rate | 360 to 465 | Intense arm and trunk work with hand tools or machines;<br>Carrying heavy material, shovelling;<br>Sledgehammer work, sawing; planning or chiselling hard wood, hand mowing, digging;<br>Walking (5,5 to 7 $km \cdot h^{-1}$) on the level, even path, solid with load ≤ 20 kg;<br>Walking (3,5 to 5 $km \cdot h^{-1}$) on levelled but irregular - unstable ground with load ≤ 20 kg;<br>Walking (2,5 to 3 $km \cdot h^{-1}$) on stable ground uphill (≤ 5 %) with load ≤ 10 kg;<br>Pushing or pulling heavily loaded hand carts or wheelbarrows;<br>Chipping castings, concrete block laying. |
| 4 Very high metabolic rate | > 465 | Intense activity at fast to maximum pace;<br>Working with an axe; intense shovelling or digging; Climbing stairs, ramp or ladder;<br>Walking (> 7 $km \cdot h^{-1}$) on the level, even path, solid, with or without load;<br>Walking (> 5 $km \cdot h^{-1}$) on levelled but irregular - unstable ground with or without load;<br>Walking (> 3 $km \cdot h^{-1}$) on stable ground uphill (≥ 5 %) with or without load;<br>Running (> 6 $km \cdot h^{-1}$). |

# Annex B
## Evaluation of the metabolic rate at level 2, *Observation*

### B.1 Evaluation of the metabolic rate of a specific activity

Data and formulas are presented for the evaluation of the metabolic rate

- at rest
- when walking with/without load
- when going up or down stairs and ladders
- when lifting — lowering loads
- for activities without displacement
- for other specific activities

**a) Metabolic rate at rest**

The metabolic rate at rest, for a seated person can be estimated by the following expressions as a function of the body surface:

$M_0 = 60 \cdot A_{Du}$ for men

$= 55 \cdot A_{Du}$ for women

where

$M_0$ is the metabolic rate, W;

$A_{Du}$ is the body surface area, m$^2$ given by $A_{Du} = 0{,}007184 \cdot W_b^{0{,}425} \cdot H_b^{0{,}725}$

where

$W_b$ is the body mass, kg;

$H_b$ is the body height, m.

**b) Metabolic rate when walking/running with/without load**

— For walking at velocities

$< 6$ km·h$^{-1}$: $M = (0{,}5 + 0{,}37 \cdot v_w + 0{,}2 \cdot v_w \cdot G) \cdot (W_b + L)$

— For running at velocities

$\geq 6$ km·h$^{-1}$: $M = (0{,}5 + 0{,}75 \cdot v_w + 0{,}1 \cdot v_w \cdot G) \cdot (W_b + L)$

where

$M$ is the metabolic rate, W;

$L$ is the load carried by the person, kg;

$v_w$ is the walking/running speed, km·h$^{-1}$;

$G$ is the ground slope, %.

**c) Metabolic rate when going up or down stairs and ladders**

**Stairs**

— going up

$M = (0{,}42 + 0{,}61 \cdot V_v) \cdot (W_b + L) = (0{,}42 + N_{steps}/10) \cdot (W_b + L)$

— going down

$M = (0{,}42 + 0{,}21 \cdot V_v) \cdot (W_b + L) = (0{,}42 + N_{steps}/28) \cdot (W_b + L)$

**Ladder**

— going up

$M = (2{,}78 + 1{,}04 \cdot V_v) \cdot (W_b + L) = (2{,}78 + N_{rungs}/4) \cdot (W_b + L)$

— going down

$M = (1{,}98 + 0{,}17 \cdot V_v) \cdot (W_b + L) = (1{,}98 + N_{rungs}/23) \cdot (W_b + L)$

where

$V_v$ is the vertical speed in m·min$^{-1}$;

$N_{steps}$ is the number of steps of stairs of height = 17 cm per min (1m·min$^{-1}$ = 5,88 steps·min$^{-1}$);

$N_{rungs}$ is the number of rungs of ladders of height = 25 cm per min (1m·min$^{-1}$ = 4 rungs·min$^{-1}$).

**d) Metabolic rate when lifting – lowering loads:**

$M = M_0 + \Delta M$

**Table B.1 — Formulas for the evaluation of the increase of metabolic rate $\Delta M$ (in W) when carrying — lifting — lowering loads**

| Task | $\Delta M$ W |
|---|---|
| Idle (Sit/Stand) and Hold: | $4{,}12 \cdot L$ |
| Lifting (Stoop) | $(0{,}09 \cdot W_b + L \cdot \mathrm{H}) \cdot F$ |
| Lifting (Arm) | $(0{,}02 \cdot W_b + 1{,}45 \cdot L \cdot H) \cdot F$ |
| Lifting (Squat) | $(0{,}14 \cdot W_b + 1{,}75 \cdot L \cdot H) \cdot F$ |
| Lowering (Stoop) | $(0{,}08 \cdot W_b + 0{,}47 \cdot L \cdot H + 0{,}726) \cdot F$ |
| Lowering (Arm) | $(0{,}03 \cdot W_b + 0{,}84 \cdot L \cdot H) \cdot F$ |
| Lowering (Squat) | $(0{,}14 \cdot W_b + 0{,}49 \cdot L \cdot H) \cdot F$ |

where

$\Delta M$ is the increase of metabolic rate, W;

$F$ is the average rate of moves, move·min$^{-1}$;

$H$ is the height of lift, m.

**e) Metabolic rate for activities without displacement**

**Table B.2 — Metabolic rate (W) for a seated person as a function of work intensity and body segment involved**

| Body segment | Metabolic rate W | | |
|---|---|---|---|
| | Light work intensity | Medium work intensity | Heavy work intensity |
| Both hands | 125 | 155 | 170 |
| One arm | 160 | 200 | 235 |
| Both arms | 215 | 250 | 290 |
| The body | 325 | 440 | 605 |

**Table B.3 — Increase of the metabolic rate $\Delta M$ (W) for body postures**

| Body posture | $\Delta M$ W |
|---|---|
| Sitting | 0 |
| Kneeling | 20 |
| Crouching | 20 |
| Standing | 25 |
| Standing stooped | 35 |

**f) Metabolic rate for other specific activities**

**Table B.4 — Metabolic rate (W) for specific activities**

| Activity | Metabolic rate W |
|---|---|
| Pushing or pulling a tip-wagon, 3,6 km·h$^{-1}$, even path, solid | |
| pushing force: 12 kg | 520 |
| pulling force: 16 kg | 675 |
| Pushing a wheelbarrow, even path, 4,5 km·h$^{-1}$, rubber tyres, 100 kg load | 415 |
| Filing iron 42 file strokes/min | 180 |
| 60 file strokes/min | 340 |
| Work with a hammer, 2 hands, mass of the hammer 4,4 kg, 15 strokes/min | 520 |
| Carpentry work hand sawing | 395 |
| machine sawing | 180 |
| Hand planning | 540 |

| Activity | Metabolic rate<br>W |
|---|---|
| Bricklaying, 5 bricks/min | 305 |
| Screw driving | 180 |
| Digging a trench | 520 |
| Home activities light | $2{,}5 \cdot M_0$ |
| moderate | $3{,}5 \cdot M_0$ |
| heavy | $4{,}5 \cdot M_0$ |

## B.2 Evaluation of the average metabolic rate (in watts) during a period of time

The procedure is as follows:

a) Before the observation period:

— Fill in the details of the person under study.

— Identify each individual activity. The number of components to be considered will vary depending upon the complexity of the activity.

— Estimate the corresponding metabolic rate using the data and/or formulas given in section B1 of this annex.

b) During the observation period of time:

— Fill in the diary by noting the number of the activity and the time each time the activity is changed

c) At the end of the exposure period of time

— Calculate the total length of time spent on each activity.

— Multiply the length of time spent on activity by the corresponding metabolic rate.

— Add the values.

— Divide the sum by the total length of the observation period.

## Annex C
## Evaluation of the metabolic rate at level 3, *Analysis*

As exposed in section 7 of the standard, the following formulas make it possible to predict the (HR – M) relationship as a function of the characteristics of the person, for purely dynamic muscular work using essentially the lower limbs, in neutral environments (no heat influence on HR) for an mean fit person.

— Maximum Working Capacity MWC, W:

— Men: $(19.45 - 0.133 \cdot Age) \cdot W_{bl}$ (C1)

— Women: $(17.51 - 0.150 \cdot Age) \cdot W_{bl}$ (C2)

where Age is the age of the person, years;

$W_{bl}$ is the lean body mass, kg.

— Lean body mass $W_{bl}$:

— Men: $W_{bl} = (1,08 – W_b / (80 \cdot H_b^2) \cdot W_b$ (C3)

— Women: $W_{bl} = (0,86 – W_b / (107,5 \cdot H_b^2) \cdot W_b$ (C4)

where $W_b$ is the body mass of the person, kg

$H_b$ is the body height, m

— Resting metabolic rate $M_0$, W:

— Men: $60 \cdot A_{Du}$ (C5)

— Women: $55 \cdot A_{Du}$ (C6)

— Maximum heart rate $HR_{max}$, beats·min$^{-1}$:

— Men and women: $208 - 0,7 \cdot Age$ (C7)

— Heart rate at rest $HR_0$, beats·min$^{-1}$:

The heart rate value exceeded during 99% of the time of the HR recording, provided that the person was at rest in a neutral environment at least 5 min during the recording.

In the conditions mentioned above, the metabolic rate (M) can be derived from the heart rate $HR_m$ using the following expression:

$$M = M_0 + ( HR_m – HR_0 ) / RM \quad (C8)$$

where:

$$RM = (HR_{max} − HR_0) / (MWC − M_0) \quad (C9)$$

In these conditions, the accuracy of the estimated metabolic rate varies as a function of the metabolic rate according to the following expression:

$$CV = 17.5 - 15 / M \quad (C10)$$

Table C1 gives the coefficients de variation of M for values in the range 100 to 700 W and shows that the accuracy is in practice of 10 to 15%.

| **M (W)** | 100 | 200 | 300 | 400 | 500 | 600 | 700 |
|---|---|---|---|---|---|---|---|
| **CV (%)** | 2.5% | 10.0% | 12.5% | 13.8% | 14.5% | 15.0% | 15.4% |

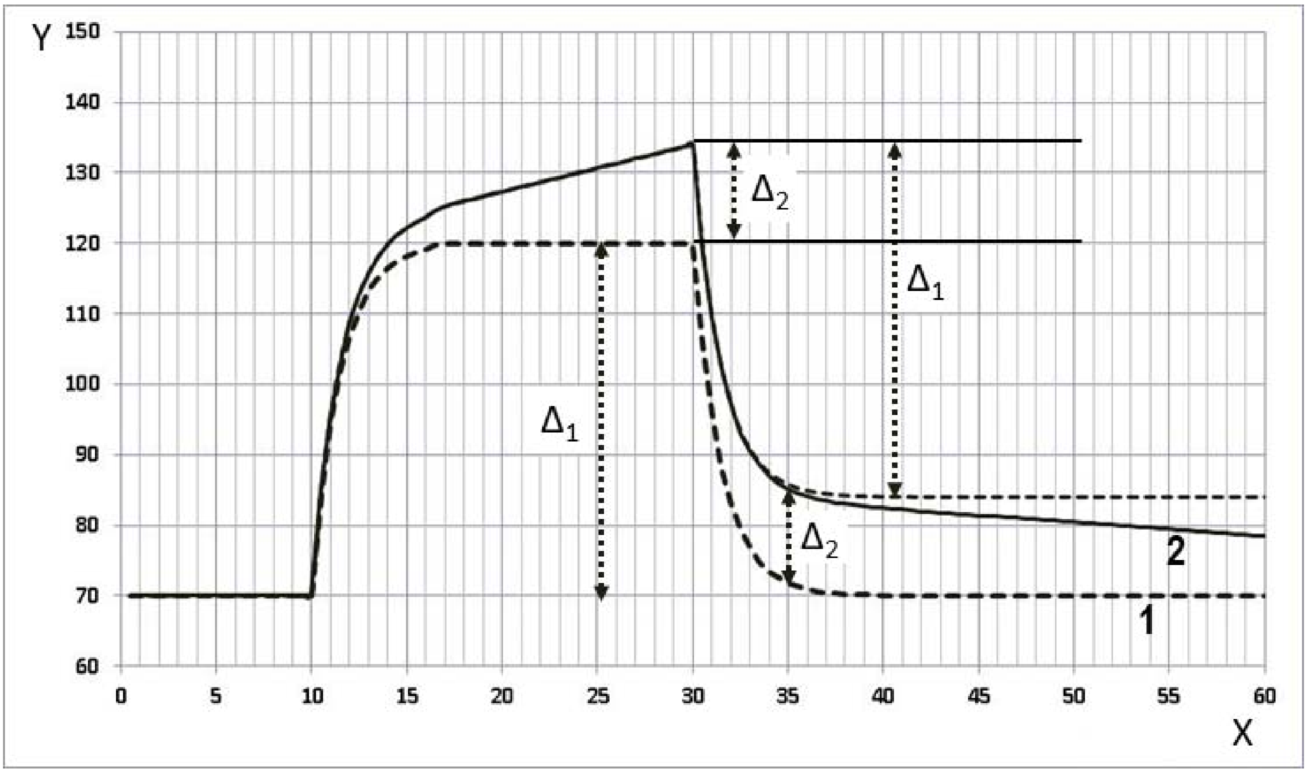
Assuming that $HR_0$ = 70 beats·min$^{-1}$ and $M_0$ = 100 W, Table C.1 provides the increase in heart rate per unit of metabolic rate RM of the relation $M$ = (HR − 70)/RM + 100 predicted as a function of the age and the weight of the person (women and men) for estimating the metabolic rate from heart rate recordings over a representative period in accordance with the method given for level 3, *Analysis*.

**Table C.1 — Value of (1/RM) in the relation *M* = (HR – 70)/RM + 100 between metabolic rate (in W) and heart rate (in beats per min), predicted as a function of the age and the lean body mass of the person (for women and men)**

| Age (Years) | Lean body mass kg | | | | | | |
|---|---|---|---|---|---|---|---|
| | **50** | **60** | **70** | **80** | **90** | **100** | **110** |
| **Women** | | | | | | | |
| 20 | 5,04 | 6,21 | 7,38 | 8,55 | 9,73 | 10,90 | 12,07 |
| 25 | 4,88 | 6,02 | 7,16 | 8,31 | 9,45 | 10,59 | 11,73 |
| 30 | 4,71 | 5,82 | 6,93 | 8,04 | 9,15 | 10,26 | 11,38 |
| 35 | 4,52 | 5,60 | 6,68 | 7,76 | 8,84 | 9,92 | 11,00 |
| 40 | 4,32 | 5,37 | 6,42 | 7,46 | 8,51 | 9,55 | 10,60 |
| 45 | 4,11 | 5,12 | 6,13 | 7,14 | 8,15 | 9,16 | 10,17 |
| 50 | 3,89 | 4,86 | 5,83 | 6,80 | 7,78 | 8,75 | 9,72 |
| 55 | 3,65 | 4,58 | 5,51 | 6,44 | 7,37 | 8,30 | 9,23 |
| 60 | 3,39 | 4,28 | 5,16 | 6,05 | 6,94 | 7,82 | 8,71 |
| 65 | 3,11 | 3,95 | 4,79 | 5,63 | 6,47 | 7,31 | 8,15 |
| **Men** | | | | | | | |
| 20 | 5,96 | 7,32 | 8,67 | 10,03 | 11,38 | 12,73 | 14,09 |
| 25 | 5,86 | 7,20 | 8,54 | 9,88 | 11,21 | 12,55 | 13,89 |
| 30 | 5,75 | 7,07 | 8,39 | 9,72 | 11,04 | 12,36 | 13,68 |
| 35 | 5,64 | 6,94 | 8,24 | 9,55 | 10,85 | 12,15 | 13,46 |
| 40 | 5,51 | 6,80 | 8,08 | 9,37 | 10,65 | 11,94 | 13,22 |
| 45 | 5,38 | 6,65 | 7,91 | 9,18 | 10,44 | 11,70 | 12,97 |
| 50 | 5,24 | 6,49 | 7,73 | 8,97 | 10,21 | 11,46 | 12,70 |
| 55 | 5,09 | 6,31 | 7,53 | 8,75 | 9,97 | 11,19 | 12,41 |
| 60 | 4,93 | 6,13 | 7,32 | 8,52 | 9,71 | 10,91 | 12,10 |
| 65 | 4,76 | 5,93 | 7,10 | 8,26 | 9,43 | 10,60 | 11,77 |

# Annex D
## Correction of the heart rate measurements for thermal effects

Figure E.1 shows the procedure to be followed for the correction of the heart rate measurements for the thermal component of heart rate ($\Delta HR_T$). In this example, an experiment with 10 minutes of rest, followed by 20 minutes of work and 30 minutes of rest is considered.




**Key**

X time, min

1 evolution of heart rate in an environment without thermal constraint

2 evolution of heart rate in an environment with thermal constraint

Y heart rate, beats·min$^{-1}$

$\Delta_1$ elevation of heart rate of metabolic origin ($\Delta HR_M$), beats·min$^{-1}$

$\Delta_2$ elevation of heart rate of thermal origin ($\Delta HR_T$), beats·min$^{-1}$

**Figure E.1 — Correction of the heart rate measurement for thermal effects**

Curve 1 describes the evolution of heart rate (HR) as a function of time when the task is performed in an environment without thermal constraint: the HR at rest ($HR_0$) of 70 beats·min$^{-1}$ (bpm) increases, as an example, to 120 bpm ($\Delta_1 = \Delta HR_M$ = 50 bpm) during the work phase (steady state reached after 5 minutes) and decreases back to 70 bpm during the final rest period (steady state again reached after 5 minutes).

Curve 2 describes the evolution of heart rate caused by the rise in body temperature due to work load or due to a hot environment in the same experiment: during the work phase, the heart rate increases this time, for example, to 134 bpm: $\Delta HR = \Delta_1 + \Delta_2 = \Delta HR_M + \Delta HR_T$.

After 5 minutes of rest in an environment without thermal constraint, the elevation of HR of metabolic origin ($\Delta_1 = \Delta HR_M$ = 50 bpm) will be recuperated while the increase of thermal origin ($\Delta_2 = \Delta HR_T$ = 14 bpm in this example) will be recuperated very slowly at a rate depending upon the recovery conditions.

The HR recorded after 5 minutes of recovery is therefore considered equal to $HR_0 + \Delta_2 = HR_0 + \Delta HR_T$.

In the case of constant metabolic rate during the work phase, it can be assumed that the thermal component $\Delta_2 = \Delta HR_T$ increases linearly as a function of time (although this is correct only as long as the body temperature increases linearly). The metabolic rate can therefore be estimated from the average heart rate during the work phase minus half of the elevation of HR measured at the 5$^{th}$ minute of recovery.