Assessment of the usefulness of software applications for estimating human energy expenditure in workplace organization

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Abstract: The paper presents an assessment of the practicability of four software applications selected from those available in the Polish market to estimate and analyze energy expenditure in the context of their usefulness in design and organization of workplace in enterprises operating in Poland. Research questions are formulated, physiological, regulatory and functional guidelines are discussed, based on which assessment criteria are developed. Presented are averaged results of the rating performed independently by three experts and five occupational safety and health officers employed at different manufacturing plants.
The study showed that none of the applications satisfied a majority of the developed criteria at once. They are mainly useful for estimating energy expenditure for male workers but they do not provide a full representation of compliance with the current statutory regulations. Further, independent analysis based on the records of generated results is either incomplete or hindered by the imposed way of value entry which requires that additional calculations be first performed. Based on the results of a comparative analysis of the functionalities offered by the applications, guidelines for software applications yet to be developed for estimating and analysis of human energy expenditure at the workplace are proposed.

Key words: energy expenditure, computer aided analysis, workplace organization

1. Introduction

Poland is one of a few countries where determining worker energy expenditure at work task performance is required by law. Information about how physically demanding work is (the measure of energy expenditure) for each job is essential not only for the comparison with the applicable regulations concerning maximum allowable values for regular work activity but also for work planning and undertaking proactive action directed at limiting adverse health effects of work. The rate of energy expenditure per shift should be taken into account by employers during the design of work organization

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DOI: 10.25944/znmwse.2018.04.6378

for a given job, establishing staffing levels required for specific work, planning rest breaks, frequency of periodic medical examinations, selection of work clothing thermal insulation, appropriation of employer-provided preventive meals and beverages, etc. For it is common knowledge that physically demanding work increases the risk of musculoskeletal system disorders, is one of the causes of accelerated degenerative changes (especially, in the spine) and related conditions, and that its multiannual performance is the cause of accelerated decline in physical exercise capacity (Makowiec-Dąbrowska et al., 1999). Physically heavy work should also be considered as a risk factor for circulatory system disorders such as hypertension and ischaemic heart disease (Makowiec-Dąbrowska, 1995; Konarska, Kurkus-Rozowska, Krokosz and Furmanik, 1994; Koradecka and Bugajska, 1999; Koradecka, 2010). In the era of an aging society, it is extremely meaningful for employers to be knowledgeable about energetic cost of work.

Despite the fact that Polish law requires that worker energy expenditure at work task performance be established, none of the regulations unequivocally specifies what methods should be applied to measurements and what the acceptable measurement error is (Byrska, 2013). On this account, measurements of energy expenditure need not be performed by accredited laboratories. Energy expenditure may as well be estimated by the employer alone. There are a number of methods for the employer to choose from, among others, direct calorimetry, indirect calorimetry (also known as the gasometric method), continuous heart rate monitoring, tabular methods. Principles of their application, their advantages and disadvantages have been presented in many publications (Lehmann, 1966; Konarska, 1985; Rogoziński 1988; Pałka 1990; Makowiec-Dąbrowska et al., 2000; Grzywiński, Mederski and Bembenek, 2014), and therefore, will not be discussed in any detail in the foregoing article.

Some of the methods of energy expenditure determination, e.g. direct calorimetry, indirect calorimetry, heart rate measurements require specialized equipment (Makowiec-Dąbrowska, Radwan-Włodarczyk, Koszada-Włodarczyk and Jóźwiak, 2000), which frequently is beyond small and medium-size enterprises as well as what professional occupational health and safety service providers can afford. Besides, measurement instruments may often disrupt the manufacturing process or constrain workers' mobility. For this reason, if the employer wishes to determine energy expenditure on their own, most often the employer will use methods of estimating, chronometric-tabular methods, that do not require additional measuring instruments, e.g. the tabular method by G. Lehmann (Lehmann, 1966) or metabolic rate assessment compliant with the standard PN-EN ISO 8996:2005 *Ergonomics of the thermal environment. Determination of metabolic rate*. Students pursuing degrees related to ergonomics, occupational health and safety, production management and engineering learn these methods. These methods are allowed to be used when developing reports for inspection agencies: the National Labour Inspectorate, Revenue Service. They are also recommended by state research institutes in Poland, e.g. the Central Institute for Labour Protection in its *Companion to the statutory law of December 19 2008 on bridging pensions. Principles of classification of work in special conditions and of special character* (MPiPS, CIOP-BIP, 2009). According to a number of different authors (Konarska, 1985; Koradecka and Sawicka, 1987; Rogoziński, 1988; Pałka 1990; Dębowski and Spioch, 1992; Grzywiński et al., 2014), application of chronometric-tabular methods allows for determining energy expenditure with a precision of approximately 10–20% compared to the results obtained with indirect calorimetry methods. It needs to be borne in mind that these methods are subjective to a large extent and their application by people without considerable experience leads to serious errors. Therefore, they should be treated as approximate and preliminary and as those whose results may indicate the need to conduct further in-depth investigation (Makowiec-Dąbrowska et al., 2000). In addition, according to the standard PN-EN ISO 8996:2005, tabular methods should not be used to analyze energy expenditure in cold and hot microclimate.

Tabular methods are fairly effort- and time-intensive, which OSH service specialists and people responsible for workplace organization and design tend to complain about. They demand that precise chronometry of a working day be prepared, each body posture and range of body parts involved in each action performed by the worker at work be identified, energy expenditure be determined, and finally, an analysis of the energetic cost of work be calculated. This discourages designers, OSH service and even business owners from assessing energy expenditure. Useful in this regard may be software applications that would reduce the time required for estimating and analysis of the energetic cost of work.

With these considerations underlying the study, the following objective was set:

- to develop criteria for assessment of available computer programmes for estimating and analysis of energy expenditure in terms of their usefulness for workplace organization and design at enterprises operating in Poland. The developed criteria will then be useful as guidelines for programmes that are yet to be developed;
- to evaluate applications for estimating and analyzing energy expenditure available in the Polish market based on the developed criteria.

2. Materials and methods

In reference to the objective of the study, the following research questions were formulated, which facilitated the development of evaluation criteria for computer programmes for estimating and analysis of energy expenditure:

- What information about jobs, workplaces and workers should be expected to be required by the application?
- What (information) should be included in the results of estimating energy expenditure?
- What components should energy expenditure analysis include?

Answers to these questions were arrived at based on critical analysis of the literature, available reports on energy expenditure measurements, and brainstorming with the participation of three experts on determining energy expenditure in the workplace. The group of experts was comprised of two employees of the Ergonomics Laboratory in the Faculty of Management and Production Engineering, Lodz University of Technology, and one long-time employee of the Nofer Institute of Occupational Medicine in Łódź.

Evaluation criteria were developed for each stage of energy expenditure estimation and analysis.

Applications for analysis were selected with the aid of the Google web browser. The search was based on a combination search queries: computer programme, application, calculator, measurement, determining, estimating, energy expenditure, metabolic rate. Based on the query, the browser turned out eight programmes/ applications/ calculators.

The criteria for qualification for further study were the following:

– application developed by a recognized in Poland science, research, inspection institution or a research laboratory,
– accessibility—free application or, in the case of paid applications, availability of a demonstration or testing version of the application,
– language used in the application—Polish was a necessary requirement,
– adequacy—application expected to enable estimating energy expenditure under industrial conditions for particular jobs.

Based on the above criteria, four applications/ calculators were excluded from further analysis as they were directed primarily at people pursuing sports activities. Three applications that satisfied the above criteria qualified for analysis as well as one that only failed to meet one criterion (the first):

– freeware *Basic energy expenditure calculator developed by Piotr Lubaś—National Labour Inspectorate District Labour Inspectorate in Szczecin* (PIP-OIP Szczecin, 2017; Lubaś, 2011),
– freeware *Interactive occupational risk assessment system IRYS—Central Institute for Labour Protection, State Research Institute* (CIOP-PIB, 2005),
– shareware *'Laborant' computer software* (Program 'Laborant', 2013) developed by Andrzej Uzarczyk, the owner of the company An-Lab Ochrona Środowiska i Bezpieczeństwo Pracy (An-Lab Environmental Protection and Occupational Safety), which provides technical consulting and training programmes for laboratories monitoring work environment, assists laboratories in the implementation of new and improvement of already accredited test methods in compliance with the international standard ISO/IEC 17025. In 1995–2007 he worked as chief specialist in the District Labour Inspectorate in Gdańsk,
– shareware *Asystent BHP 8.0* (Aplikacja Asystent BHP, 2017) by TARBONUS, a company which has been in occupational health and safety publishing, consulting and training business since 1991.

Rating of the applications was presented in the form of a matrix. Each criterion could be awarded a rating of 0 to 5 points. 5 points was a very good rating, whereas 0 points was the worst rating. The applications were rated by three experts who had previously developed the application evaluation criteria and by five OSH specialists from different manufacturing companies in the Łódź Voivodeship. All of the OSH specialists had experience in estimating energy expenditure with tabular methods. The participants of the study were given a week time to test the selected applications. The raters were provided with: the selected applications, user handbooks supplied by the application developers, the table with the criteria to be rated and explanatory notes related to the point scale for each criterion. Averaged results were presented in the matrix because the ratings awarded by the experts were much the same as the ratings given by the OSH specialists.

3. Criteria for the assessment of software applications for estimating energy expenditure

Stage I: Worker, job and workplace characteristics

To proceed with the measurement of energy expenditure, the first step should be to collect information about jobs, workplaces and workers and that is why the application should make it possible to input the following data, among others: the date of the measurement; the name of the job; location of the workstation; a short characteristics of the workers (staffing level, sex, age, body height, body weight); a description of working time (shift duration, the number and duration of rest breaks, shift schedule, overtime, etc.); the scope of duties and performed work tasks; a list of machines, devices, tools used in the workstation; microclimate indicators; specification of personal protective equipment; characteristics of work clothing; information whether employer-provided preventive meals/ beverages are supplied.

Stage II: Chronometry of a working day

The next step is to prepare a chronometric description of a working day—a snapshot of a working day. The application should allow for the input of standard activities for each job, grouping them into cycles, and determining their duration.

Stage III: Measuring/ estimating energy expenditure

To establish energy expenditure, the analyzed applications used the metabolic rate determination method compliant with the standard PN-EN ISO 8996:2005 or a simplified chronometric-tabular method by G. Lehmann. To facilitate input of data, the applications should provide for a selection of characteristics compatible with these methods.

Stage IV: Calculating energy expenditure

The application should be able to automatically calculate energy expenditure per minute, per activity and per the entire shift for both males and females. The record of the generated results should allow the user to analyze energy expenditure including produce graphs, perform additional calculations e.g. of time used for very light, light, medium heavy, heavy, and very heavy work, etc. Furthermore, the application should enable the user to change the units of measurement in which the values of energy expenditure are calculated. By default, energy expenditure is given in kilojoules (kJ) or kilocalories (kcal) per unit of time. Energy expenditure for calculating heat balance of the body required for determining thermal stress and microclimate is given in watts (W) per unit body surface area (m^2).

Stage V: Analysis of energy expenditure

The application should facilitate analysis and estimating in terms of physiological and statutory requirements. This functionality is especially important for designers and engineers who, unlike OSH specialists, might not have undergone prior training in ergonomics or occupational health and safety.

Physiological requirements for energy expenditure which should be factored in the application

In Poland, pursuant to recommendations of the Nofer Institute of Occupational Medicine in Łódź and the Central Institute for Labour Protection—State Research Institute, assessments of physical demands of work (how heavy work is) are effected by comparing the measure of the planned energy expenditure to physiological energetic standards which specify acceptable ranges for regular everyday work. Table 1 illustrates a classification of work by its heaviness adopted in Poland. It was developed in a manner which favours people aged 30–35 of an average physical exercise capacity affording them the greatest protection against overexertion, and was based on the principle that workers should not exceed 30% of their maximum physical ability when performing work tasks (Ilmarinen, 1992a; Ilmarinen, 1992b).

Table 1. Work heaviness categories based on the net energy expenditure

Work heaviness categories	Males		Females	
	[kJ/min]	[kJ/8 h]	[kJ/min]	[kJ/8 h]
Very light	up to 5	up to 1256	up to 3.5	up to 837
Light	5–10	1256–3350	3.5–7.5	837–2930
Moderately heavy	10–20	3350–6280	7.5–12.5	2930–4187
Heavy	20–30	6280–8374	12.5–20	4187–5024
Very heavy	>30	>8374	>20	>5204

S o u r c e: Makowiec-Dąbrowska, 1988; Makowiec-Dąbrowska et al., 1999; MPiPS, CIOP-BIP, 2009.

The classification of work by its heaviness can be useful for assessment of dynamic work. Significant static loads limit blood circulation in the involved muscles, which reduces the ability to perform more intense labour. Considering the possibility of decreased ability for exertion when working under great static loads, it is recommended that the boundary values for energy expenditure rates by the grade of work heaviness be lowered by 20% (Makowiec--Dąbrowska et al., 1999).

Physically demanding work means a subjectively experienced or objectively observable reaction of the body to performing work the intensity of which exceeds the limits of optimal load or a reaction to performing work of optimal intensity but under working conditions which cannot be considered optimal. Of the factors that determine how physically demanding work is, related to the work itself, the first group are factors derived from the intensity and type of the physical effort. Work can be deemed physically demanding when it is heavy or very heavy in the sense of an aggregate energy expenditure, when it involves great static physical effort and a high degree of monotypicality of work motions. An additional element deciding whether work is regarded as physically demanding is irregular distribution of the intensity of physical effort during the working day and occurrence of the so-called peak workloads during which oxygen consumption exceeds 50% of individual maximum capacity. Since maximum exertion capacity deteriorates with age, the rates of energy expenditure for peak workload periods also decrease. For young females (20–29 years old) it is 20 kJ/min, whereas for 50 years old and older women—12,5 kJ/min. For males, the rates are 33.5

kJ/min and 20.9 kJ/min respectively. Occurrence of peak workloads should be regarded as a reason for work to be deemed physically demanding regardless of whether they are offset with rest breaks to such an extent that the total energy expenditure is modest (Makowiec--Dąbrowska, 1999).

Teresa Makowiec-Dąbrowska (1999) of the Nofer Institute for Occupational Medicine in Łódź recommends providing workers with additional rest breaks, on top of the statutory breaks required by the Labour Code. The purpose of rest breaks is to prevent a decline in physical exercise capacity as fatigue sets in, which is a natural, even physiological, consequence of any work.

It follows therefore that the software application should perform analysis and estimation of energy expenditure with regard to:

– the work heaviness category per shift and per each activity performed by the worker, separately for men and women (both for dynamic and static work—having regard for the aforementioned classification and guidelines),
– the work heaviness category per shift and per specific activities performed by the worker separately for women aged 50+ and men aged 50+ (both for dynamic and static work—having regard for the aforementioned classification and guidelines),
– the occurrence of peak loads, separately for women and men,
– arrangement of additional rests breaks on top of the statutory breaks required by the Labour Code,
– possible overtime work.

Regulatory requirements for energy expenditure

In May 2017, Polish law was significantly amended as regards allowable limits for energy expenditure, maximum weight of loads for manual handling and applicable force required of the worker to put an object into motion. The changes were necessitated by the amendments to Article 176 of the Labour Code, which included a new delegation of authority to specify arduous, hazardous, and harmful labour that only pregnant and breastfeeding women will be prohibited from performing. Allowable limits of net energy expenditure per work shift for casual workers have been specified: *for men and women* in the Regulation of the Minister of Labour and Social Policy of 14 March 2002 on occupational safety and health for manual handling labour and other physically demanding labour (Dz.U. no. 26, entry 313 with amendments; no. 82, entry 930; no. 56, entry 462; no. 0, entry 854); *for pregnant and breastfeeding women* in the Regulation of the Council of Ministers of 4 April 2017 on the specification of labour arduous, hazardous, and harmful to pregnant and breastfeeding women (Dz.U. of 2017, entry 796).

The said regulations do not specify unequivocal energy expenditure limits by age and physical condition of workers. Pursuant to the *Methodological guidance for preventive health examination of workers* included in the Regulation of the Minister of Health and Social Policy of 30 May 1996 on medical examination of workers, the scope of preventive healthcare for workers, and medical certification for purposes specified in the Labour Code (Dz.U. of 1996 no. 69, entry 332 with later amendments), occupational medicine practitioners should take into account age related differences and physiological changes during the preliminary and periodic medical examination of workers. For physical work with energy expenditure exceeding 1500/8 hours (6280 kJ/8 hours) or 3 kcal/min (12.5 kJ/min) for men and 1000 kcal/8 hours (4187 kJ/8 hours) or over 2 kcal/min (8.3 kJ/min) for women, periodic medical examination should be administered every 5 years and for workers aged 45+—every 3 years.

Physically heavy work entails certain additional entitlements for the worker and responsibilities for the employer. Pursuant to the effectual regulation of the Council of Ministers of 28 May 1996 on employer-provided preventive meals and beverages, the employer is required to provide free preventive meals and beverages for employees who work in particularly demanding conditions.

Another act of law which specifies additional worker entitlements and employer responsibilities due to heavy and very heavy physical labour is the statutory act of 19 December 2008 on bridging pensions (Dz.U. of 2017, entry 664 with later amendments). The law applies to people who, based on performing work in special conditions or of special character, are eligible to file for a new type of benefit, a bridging pension, before reaching retirement age. The premise for establishing criteria for the specification of work the performance of which establishes an obligation to pay mandatory contributions to the Bridging Pensions Fund and entitles the payee to a bridging pension was that the worker's capacity for performing work diminishes with age in relation to declining psychophysical abilities of the worker. This relates to work performed in special conditions or of special character, conditioned by the forces of nature, technological processes or particular demands that older workers may not be able to meet, whereas available proactive and preventive technical, organizational and medical measures are insufficient to reduce risks that such work poses for the welfare and well-being of the worker. In Annex no. 1 to the statutory act listed are types of work in special conditions.

It needs to be borne in mind that pursuant to the Regulation of the Minister of Labour and Social Policy of 26 September 1997 on general regulations concerning occupational health and safety (Dz.U. of 2003 no. 169, entry 1650 with later amendments), the temperature in work rooms should be appropriate for the type of work performed therein (work techniques and physical effort required for work performance) and not lower than 14˚C (287 K) unless technological constraints do not allow it. For those work rooms where light physical work is performed, the temperature must be at least 18˚C (291 K). Furthermore, depending on the microclimate and the rate of energy expenditure, suitable thermal insulation of work clothing should be selected for workers.

It follows from the previous discussion that the software applications should be able to analyze and estimate energy expenditure in terms of:

– legally allowable energy expenditure rates for casual work and per shift, separately for men, women, pregnant women, and breastfeeding women,
– the duty on the employer to require workers 45 years old and older to undergo periodic medical examinations every three years,
– appropriation of employer-provided meals and beverages,
– establishing eligibility for a bridging pension,
– possible overtime work,

– ensuring appropriate temperature in work rooms,
– selection of suitable thermal insulation for work clothing.

4. Characteristics of the diagnosed software applications

Basic energy expenditure calculator developed by Piotr Lubaś

The programme makes use of a simplified Lehmann's method of estimating energy expenditure at work. The application was developed with the aid of Microsoft Excel. On startup, a launch screen appears. In order to enter the name of the company, division, job title, and worker identification, the user needs to click 'Estimate identification data'. To add an activity performed by the worker the user clicks 'New activity'. A form appears where the activity is analyzed. The name of the activity and its duration need to be entered, body posture selected, body parts involved in the work and loads need to be defined. Once finished, the user clicks 'Feed data'. Further activities are entered in the same way. Once data for all activities have been entered, the application calculates energy expenditure for men and women.

Interactive occupational risk assessment system IRYS

The web-based application IRYS has been developed by the Central Institute for Labour Protection—State Research Institute. It is an online application for identification of job risks and occupational risk analysis. Energy expenditure is one of the factors in occupational risk assessment. On logging in, the user selects 'Demanding' and 'Physical effort'. A form pops up where the user needs to enter the duration of the performed activity and expenditure per minute, and select whether expenditure is calculated for juveniles. Once the chronometric description has been completed, the user clicks 'Estimate'. The application calculates energy expenditure only for men.

'Laborant' programme

On startup, a launch screen appears. The user chooses one of the methods for estimating energy expenditure: pulmonary ventilation or according to the standard PN-EN ISO 8996:2005. In the next window, the user 'Adds new job', which means that he/ she enters information about the job for which the measurement will be performed. To calculate energy expenditure, the user selects 'Input results'. A form pops up where the name of the performed activity and its duration are entered, body posture and groups of muscles under load are selected from a drop-down menu. The programme will calculate a mean metabolic rate and then, based on it, energy expenditure rate. To add more activities, the user selects 'Add record to the end'. To get a total result, the user clicks 'Calculate'. The application calculates energy expenditure only for men.

'Asystent BHP 8.0'

The programme was developed by Tarbonus company. It offers many tools useful for OSH specialists. One of them is energy expenditure calculator based on the standard PN-EN ISO 8996:2005. On launching the application, a startup window appears. To calculate energy expenditure, the user needs to select the 'Occupational risk' tab and then choose 'Energy expenditure'.

Next, the user needs to click 'Add'. A form shows up. The name of the job, organizational unit, the sex of the worker need to be entered. The user needs to decide whether calculations are to be performed for a standardized human being or whether the user him-/ herself will enter the worker's height, weight and age. When completing a chronometric description, the user needs to enter the name of the activity and select body posture and work intensity from a drop-down menu, determine the duration and select muscle groups involved in the activity. Once activity analysis is complete, the user clicks 'Add'. Input of further activities proceeds in the same manner. Once the entire chronometric description has been done, the user clicks 'OK'. In the window that shows up energy expenditure calculated for the worker (a man or a woman) is displayed.

5. Assessment of the selected software applications

The results of the evaluation of the selected software applications are presented in Table 2. In the matrix, averaged results are given because the ratings awarded by the experts, except for one criterion, were much the same as the ratings provided by the OSH service specialists.

For the first criterion, the highest rating was awarded to 'Laborant', although the rating ranked in the middle of the scale (3), which means that from all of the applications this one supported the entry of the greatest amount of data specified for the criterion. Worse ratings were given to: 'Asystent BHP 8.0', IRYS—application by PIP. None of the four applications allowed for the input of a list of personal protective equipment, characteristics of work clothing, information about employer-provided meals/ beverages. PIP's application received the highest possible rating for the second criterion. Lower ratings were given to 'Laborant' and 'Asystent BHP 8.0' which did not give the possibility of entering the duration of an activity below 1 minute. IRYS application has the same limitation and furthermore, it does not allow the user to enter breaks or names of activities. For the third criterion, the possibility of entering characteristics in accord with the selected estimation method was rated. In the case of Piotr Lubaś's application and 'Asystent BHP 8.0', two values are possible, although in the former, only the minimum and the maximum values are given, whereas in the latter, the user may choose a mean value or enter a user-specified value, without the possibility of a selection. 'Laborant' application only allows for the entry of a mean value, whereas IRYS offers no prompts as for the range and the user needs to specify the value on his/ her own. For the fourth criterion, the rating of 5 was given to IRYS and 'Asystent BHP 8.0', whereas 0 to the application by Piotr Lubaś and 'Laborant', where the user cannot enter these data. All of the applications automatically calculate energy expenditure for men for each activity, for each entire task and per shift.

In the case of women, 'Asystent BHP 8.0' outputs values for an entire task and per shift, the PIP application only per shift albeit not without a calculation error (on the account of which one point was deducted). IRYS and 'Laborant' do not provide calculations for the other sex. The criterion concerning analysis and estimation of energy expenditure in various terms revealed weakness of all of the applications since a vast majority of analysis cannot be performed. IRYS analyzes the calculated rates in terms of the work heaviness category but only to a limited extent, and so does 'Laborant'. IRYS provides an analysis with regard to the legally allowable rates of energy expenditure for casual work and per shift for both sexes and for pregnant women. Piotr Lubaś's application includes only two of these criteria—work per shift and work performed by women.

The ratings for the criterion related to the possibility of independent analyses (the same as for the previous point) based on the records of the results without prior additional calculations are exaggerated compared to the functionalities that these applications really offer. It needs to be taken into consideration that they do not support the input of microclimate characteristics, which precludes determining beyond any doubt whether the worker is entitled to an employer-provided meal and beverage or what work clothing the worker should be equipped with. Unavailability of information about energy expenditure per minute makes it impossible to perform an analysis as regards exceeding legal limits, work heaviness categories per minute, periodic medical examination of workers 45+, peak loads, etc. Some of the applications require the user to convert measurement units in order to perform certain analyses. The ratings awarded by individual raters differed for this criterion. This indicates that different scope of information is found sufficient by users of such applications who are to a varying extent prepared to judge their merits.

Only PIP's application permits the user to record the generated results in the form of graphs and to perform additional calculations. None of the applications provides automatic updates and none allows the user to update guidelines related to acts of law or legally allowable limits of energy expenditure.

Table 2. Results of the evaluation of the selected software applications[1]

Evaluation criterions	PIP—by P. Lubaś	IRYS	Laborant	Asystent BHP 8.0
1. The application supports input of the following data, among others: date of measurement; name of the position; location of the workstation; short characteristics of workers; characteristics of the working time; scope of duties and tasks performed; specification of machines, devices, tools used in the workstation; microclimate indicators; specification of personal protective equipment; characteristics of work clothing; information concerning employer-provided preventive meals and beverages. (0—none of the above points supported, 1—8 to 10 points unsupported, 2—5 to 7 points unsupported, 3—3 to 4 points unsupported , 4—1 or 2 points unsupported, 5—all points supported)	1.5	1	3	2
2. The application supports input of typical tasks, rest breaks, and grouping them into cycles, entering the duration of these tasks including < 1 min. (0—unsupported, 1—input of only one variable supported, 2—two variables supported, 3—three variables supported, 4—four variables supported; 5—all variables supported)	5	2	4	4
3. The application supports selection of task characteristics according to the chosen estimation method for each task. (0—no selection, the user needs to enter the value him-/ herself no prompts provided, 1—no selection, the user needs to enter the value him-/ herself but a range is prompted, 2—only one possible value can be selected, e.g. min., max or mean, 3—two values supported, 4—three values supported: min., mean and max., 5—min., max mean, and a user-provided values supported)	3	0	2	3
4. The application supports independent entry of energy expenditure rates by the user within the provided ranges according to the estimation method of choice. (0—unsupported, 5—supported)	0	5	0	5
5. The application automatically calculates energy expenditure for men per: minute of each task, entire task, entire shift. (0—unsupported, 5—supported)	 5 5 5	 5 5 5	 5 5 5	 5 5 5
6. The application automatically calculates energy expenditure for women per: minute of each task, entire task, entire shift. (0—unsupported, 5—supported)	 0 0 4	 0 0 0	 0 0 0	 0 5 5

[1] The point scale is discussed only for the criteria that were awarded at least 1 point by at least one rater—study participant.

Evaluation criterions	PIP—by P. Lubaś	IRYS	Laborant	Asystent BHP 8.0
7. The application automatically analyzes and estimates the rate of energy expenditure in terms of:				
a) work heaviness category per shift and per individual tasks performed by the worker, separately for men and women, both for dynamic and static labour, having regard for the previously discussed classifications and guidelines (0—unsupported, 1—only one or two criteria taken account of, 2—three criteria, 3—four criteria, 4—five criteria, 5—all criteria),	0	1		0
b) work heaviness category per shift and for each individual task performed by the worker, separately for women 50+ and men 50+ (both for dynamic and static labour having regard for the previously discussed classifications and guidelines),	0	0	0	0
c) peak workloads separately for women and men,	0	0	0	0
d) providing workers with additional rest breaks apart from the ones required by the Polish Labour Code,	0	0	0	0
e) possible overtime,	0	0	0	0
f) legally allowable rates of energy expenditure for casual work and per shift separately for men, women, pregnant women, breastfeeding women (0—unsupported, 1—only one or two criteria taken account of, 2—three criteria, 3—four criteria, 4—five criteria, 5—all criteria),	1	3,5	0	0
g) responsibility to require workers 45 years old and older to undergo periodic medical examinations every three years,	0	0	0	0
h) appropriation of employer-provided preventive meals and beverage,	0	0	0	0
i) establishing eligibility for a bridging pension,	0	0	0	0
j) ensuring suitable temperature in work rooms,				
k) selection of suitable thermal insulation for work clothing	0	0	0	0
8. The record of the obtained results allows the user to perform independent analysis of energy expenditure for points a–k above without the need for additional calculations or data sheets. (0—unsupported, 1—supported for one to two points, 2—three to five points, 3—six to eight points, 4—nine to ten points, 5—twelve points)	3.5	1	3	2
9. The record of the obtained results allows the user to generate graphs/ charts, additional calculations in the application. (0—unsupported, 5—supported, large degree of user discretion)	5	0	0	0
10. The application supports user's revisions of guidelines related to regulations or updates are provided by the application's developer.	0	0	0	0
11. The application supports user's revisions of legally allowable rates of energy expenditure.	0	0	0	0

S o u r c e: Authors' own elaboration.

7. Conclusions

The aim of the study was to analyze and assess the practicability and usefulness of the selected software applications to estimate human energy expenditure in workplace organization. Research questions were formulated which, with the participation of three experts, allowed the authors to establish criteria for the evaluation of the applications. With the aid of Google web browser and selection criteria, four applications were qualified for further analysis. Using a survey questionnaire, the three experts and four occupational safety and health service specialists rated the applications in terms of regulatory, physiological and functional guidelines.

The study showed that none of the applications satisfied a majority of the developed criteria at once. They are characterized by a range of inaccuracies and shortages such as a lack of an exhaustive automatic analysis of the heaviness of work for men not to mention for women (especially, pregnant and breastfeeding) or workers aged 45+. Further, independent analysis based on the records of generated results is either incomplete or hindered by the imposed way of value entry which requires that additional calculations be first performed. A number of users may therefore decide that the application does not support this feature since it is not sufficiently straightforward to obtain the required information.

Regulatory requirements are worth drawing attention to as they demand that human energy expenditure be calculated and appropriate action be taken in case allowable limits are exceeded, e.g. preventive meals and beverages provided, certain groups of workers prohibited from performing certain excessively heavy work. In a situation when a software application does not support comparison with the effectual regulations, it cannot be deemed sufficiently useful and practicable.

The results of the study and their analysis allow the authors to establish that the presented applications do not meet the predefined requirements to a satisfactory extent. They are mainly useful for estimating energy expenditure for male workers but they do not provide a full representation of compliance with the current statutory regulations. The authors perceive a strong need in the Polish market for a software application that would be simple to use for an average OSH service worker, engineer or employer and would enable thorough analyses at the same time. These analyses (preferably automatic, however, it would also be useful if the user were allowed to perform user-defined analysis without additional effort) should take into account physiological variation (should be able to be performed for both sexes, and also for pregnant and breastfeeding women, different age groups) in terms of meeting statutory requirements, and with the application of the criteria discussed in this research paper.

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Ocena możliwości wykorzystania aplikacji komputerowych do szacowania wydatku energetycznego w organizacji stanowisk pracy

Abstrakt: W artykule przedstawiono ocenę możliwości wykorzystania czterech wybranych, spośród dostępnych na polskim rynku, aplikacji komputerowych służących do szacowania i analizy wydatku energetycznego w kontekście ich przydatności do organizacji i projektowania stanowisk pracy w przedsiębiorstwach działających na terenie polskim. Sformułowane zostały pytania badawcze oraz przedstawiono wytyczne fizjologiczne, prawne oraz użytkowe, na podstawie których opracowano kryteria oceny. Zaprezentowano uśrednione wyniki oceny, którą przeprowadziło niezależnie trzech ekspertów oraz pięciu pracowników służby bezpieczeństwa i higieny pracy, zatrudnionych w różnych przedsiębiorstwach produkcyjnych. Przeprowadzone badania udowodniły, że żadna z aplikacji nie spełnia naraz większości z opracowanych kryteriów. Nadają się one głównie do obliczeń wydatku energetycznego pracownika płci męskiej, ale nie dają pełnego obrazu na temat spełnienia wytycznych fizjologicznych ani aktualnych wymagań prawnych. Ponadto samodzielna analiza na podstawie uzyskanych zapisów jest albo niepełna z powodu braku możliwości wprowadzania wszystkich wymaganych danych, albo utrudniona przez taki sposób podawania wartości, który wymaga dodatkowych obliczeń.

Słowa kluczowe: wydatek energetyczny, komputerowe wspomaganie analizy, organizacja stanowisk pracy