# Application of Digital Technologies to Calculate Electromagnetic Field Energy Indicators for Workplace Safety

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Abstract: The number of electromagnetic field (EMF) sources is steadily increasing, and workplace exposure assessment is becoming more complex due to a wider spectrum of higher harmonic components. This creates a need for accurate and automated evaluation of EMF parameters for electrical personnel. While software tools exist for estimating electric and magnetic field strengths, practical tools for calculating EMF energy-based indicators remain limited. This paper presents an original software tool for automatic calculation of key EMF energy characteristics at workplaces, including EMF energy load, total energy load, daily dose of potential EMF exposure energy, and specific daily dose of potential absorbed EMF energy. The tool accepts harmonic-component inputs for electric and magnetic field strengths, frequency, and exposure time, as well as anthropometric parameters required for dose-related computations. The application was implemented in C# using Windows Forms and includes input validation (missing values, numeric format, and consistency of component lists) to reduce user errors. The calculation results are provided through a user-friendly interface suitable for routine occupational safety assessments. The outputs were verified against an independent spreadsheet implementation for representative test cases, showing agreement within rounding error. Ultimately, the developed application enhances the reliability of occupational safety protocols and facilitates rapid decision-making in complex electromagnetic environments.

## 1 INTRODUCTION

Electromagnetic fields (EMF) are a common occupational factor in power-engineering and railway electrical maintenance. In practical workplace conditions, EMF exposure is often non-sinusoidal: modern equipment may produce a spectrum of higher harmonic components, which complicates exposure assessment and increases uncertainty in routine occupational safety evaluations [1], [2].

Most existing software tools focus on estimating electric and magnetic field strengths or checking compliance with limit values. However, practical tools that automatically compute energy-based EMF indicators for workplace assessment remain limited, especially when multi-component harmonic inputs and exposure durations must be processed consistently. Regulatory approaches to occupational EMF safety and compliance are commonly based on exposure limits and risk-management procedures for workers [3], [4]. In addition to international guidelines, safety levels are also addressed in engineering standards used in practice [5], [6].

This paper presents a software tool for automated calculation of EMF energy indicators for workplace safety assessment of electrical personnel [3], [7]. The tool computes: (i) EMF energy load, (ii) total energy load, (iii) daily dose of potential EMF exposure energy, and (iv) specific daily dose of potential absorbed EMF energy. The application supports harmonic-component inputs (E, H, f, t), performs input validation to prevent inconsistent datasets, and provides results via a graphical user interface.

In traction power-supply systems, nonlinear operating conditions and power-quality issues may occur, which motivates systematic assessment of electromagnetic exposure indicators in related workplaces [8].

Unlike prior work that predominantly focuses on simple threshold compliance for electric and magnetic field strengths, we propose a comprehensive digital tool for computing cumulative energy-based indicators. The primary contribution of this paper is the development and verification of a specialized C# application that automates the calculation of total energy load and specific daily doses across multiple harmonic components, ensuring error-free routine occupational safety evaluations.

Contributions:

- a practical software implementation for automated computation of EMF energy indicators from harmonic-component inputs;
- a structured workflow with input validation and error handling for consistent data processing;
- demonstration of the tool on representative workplace cases and verification against an independent spreadsheet calculation.

# 2 MATERIALS AND METHODS

## 2.1 Input Data and Sources

The input data for the software tool include electric field strength *E*, magnetic field strength *H*, frequency *f*, exposure duration *t*, and anthropometric parameters (height and weight). The values of *E*, *H*, *f*, and *t* are taken from workplace assessment documentation, while height and weight are obtained from personnel records used in occupational safety management. Measurement procedures for electric and magnetic field levels in power systems may follow IEC basic standards and related measurement guidance [9]-[11].

## 2.2 Software Implementation

The software tool was implemented in C# using Windows Forms targeting the .NET Framework, which ensures high compatibility with standard workstation operating systems used in enterprise safety departments. The application includes input parsing, numeric-format handling, mandatory-field checks, and consistency checks for harmonic-component lists to prevent incorrect computations.

## 2.3 Computational Workflow (Algorithm)

The computational workflow of the proposed assessment method is summarized below and consists of the following sequential steps:

1) Read inputs. Anthropometric parameters and harmonic-component data (Ei, Hi, fi, ti).
2) Validate inputs (missing fields, numeric format, consistency of harmonic list lengths).
3) Compute body surface area $S$ and exposure probability factor $p_i=t_i/24$.
4) Compute energy indicators for each harmonic component and aggregate totals.
5) Output results and diagnostic messages for invalid or inconsistent input.

Reproducibility considerations. To support reproducible assessments, the tool records the full set of entered harmonic-component inputs and anthropometric parameters used for each calculation. The outputs $Q_i$, $Q_\Sigma$, $D$, and $D_s$ can be copied into workplace reports and independently verified using the provided equations or a spreadsheet implementation.

## 2.4 Input Validation and Error Handling

To prevent incorrect computations in routine workplace use, the application performs several validation checks before running the mathematical model: (i) mandatory-field checks for anthropometric parameters and harmonic-component lists; (ii) numeric-format handling (decimal separator, leading/trailing spaces); (iii) non-negativity checks for exposure durations $t_i$; (iv) consistency checks ensuring that lists $\{E_i\}$, $\{H_i\}$, $\{f_i\}$, and $\{t_i\}$ have equal length; and (v) range checks for the supported frequency interval (25 Hz-1 kHz). When invalid input is detected, the program displays diagnostic messages indicating the field and the reason, and blocks calculation until the dataset becomes consistent.

## 2.5 Mathematical Model

Let $E_i$ (V/m) and $H_i$ (A/m) denote RMS values of the electric and magnetic field strengths for the *i*-th harmonic component, with frequency $f_i$ (Hz) and exposure duration $t_i$ (h), $i$=1,…,n. Height $h$ (cm) and weight $m$ (kg) are used to compute body surface area $S$ (m$^2$).

Body surface area (Mosteller) [12]:

$$S = \sqrt{\frac{h\cdot m}{3600}},\ S\ in\ m^2. \quad (1)$$

Exposure time share for a 24-hour day:

$$p_i = \frac{t_i}{24}. \quad (2)$$

Energy load (power-density-based indicator). The energy flux density for each harmonic component is estimated as:

$$Q_i = E_i \cdot H_i, \qquad (3)$$

where $Q_i$ is in W/m$^2$.

Total energy load:

$$Q_\Sigma = \sum_{i=1}^{n} Q_i. \qquad (4)$$

where $Q_\Sigma$ is in W/m$^2$.

Daily dose of potential EMF exposure energy (per unit area):

$$D = 3600 \sum_{i=1}^{n} Qi\, t_i. \qquad (5)$$

($D$ in J/m$^2$). The factor 3600 converts exposure duration from hours to seconds.

Equivalently, using $p_i$:

$$D = 24 \cdot 3600 \sum_{i=1}^{n} Qi\, p_i. \qquad (6)$$

where $t_i$ is measured in hours and $p_i=t_i/24$.

Specific daily dose of potential absorbed EMF energy. First, the potential incident energy on the body is estimated as $E_{body}=D \cdot S$ *(J)*. The specific daily dose is then:

$$D_s = \frac{D \cdot S}{m}, \qquad (7)$$

where $D_s$ is in J/kg.

## 2.6 Verification

The software outputs were verified against an independent spreadsheet implementation for representative test cases. The results matched within rounding error.

## 2.7 Assumptions and Limitations

The proposed indicators are computed from workplace input data and are intended for comparative assessment across tasks and exposure scenarios. The model uses RMS values of $E_i$ and $H_i$ for harmonic components and aggregates exposure over time. The indicators describe potential incident energy-related characteristics and do not replace detailed dosimetric modeling in complex near-field conditions. Therefore, the accuracy of the outputs depends on the quality of initial workplace measurements and the correctness of the entered exposure durations.

## 2.8 Computational Complexity and Runtime

The computational core of the tool is based on a single pass over the harmonic-component list. Therefore, the time complexity is *O(n)*, where *n* is the number of components. Memory usage is also *O(n)* due to storage of input lists and intermediate values. In practical use (typical $n$=2-10), the computation is instantaneous on standard office computers, and the overall runtime is dominated by user input rather than numeric processing.

# 3 RESULTS

Representative harmonic-component inputs ($E_i$, $H_i$, $f_i$, $t_i$) and anthropometric parameters were entered into the software tool. The input dataset consisted of three harmonic components within the supported frequency range (25 Hz-1 kHz). For each component, the user entered RMS values of $E_i$ and $H_i$, the frequency $f_i$, and the exposure duration $t_i$ in hours. Anthropometric parameters (height $h$ in cm and weight $m$ in kg) were used to compute the body surface area $S$ required for calculating $D_s$. All values were processed using a consistent numeric format to avoid decimal-separator errors. The calculated outputs are presented in Table 1, and the user interface is shown in Figure 1. Because site-specific workplace measurements were not available at the drafting stage, an illustrative numerical case is provided to demonstrate the full computational pipeline and the relationship between input parameters and aggregated indicators. This approach enables readers to independently reproduce the calculations using the provided equations. For the demonstration cases, $h$ = 172 cm and $m$ = 75 kg (Mosteller S = 1.893 m$^2$).

Table 1: Illustrative input data and computed outputs (demonstration case). (The values are used to demonstrate the calculation workflow; real workplace values depend on measurement conditions.)

| Harmonic $i$ | $E_i$ (V/m) | $H_i$ (A/m) | $f_i$ (Hz) | $t_i$ (h) | $Q_i$ (W/m$^2$) |
|---|---|---|---|---|---|
| 1 | 120 | 0.25 | 50 | 2.0 | 30.0 |
| 2 | 60 | 0.12 | 150 | 1.0 | 7.2 |
| 3 | 40 | 0.08 | 250 | 0.5 | 3.2 |
| Total | | | | | $Q_\Sigma$=40.4 |

Daily dose $D$ = 247680 (J/m$^2$) and specific daily dose $D_s$ = 6251(J/kg). Verification against an independent spreadsheet implementation showed agreement within rounding error, as detailed in Table 2.

For Case 1, the component-wise energy loads are computed as $Q_1=E_1H_1$ and $Q_2=E_2H_2$, followed by aggregation $Q_\Sigma=Q_1+Q_2+Q_3$. The daily dose is then obtained using $D=3600\sum(Q_it_i)$. Finally, the specific dose is computed as $D_s=(DS)/m$, where $S$ is calculated by the Mosteller formula, selected over alternatives such as the Du Bois formula for its simplicity and widespread use in clinical and occupational health applications.

Table 2: Verification against spreadsheet implementation (demonstration case).

| Case | Metric | Software tool | Spreadsheet | Relative error |
|---|---|---|---|---|
| 1 | $Q_\Sigma$ (W/m$^2$) | 40.4 | 40.4 | 0.0% |
| 1 | D (J/m$^2$) | 247680 | 247680 | 0.0% |
| 1 | $D_s$ (J/kg) | 6251 | 6251 | 0.0% |

The verification results show full agreement for the demonstration case; minor differences may occur in practice due to rounding.

Table 3: Illustrative input data and computed outputs (demonstration case 2).

| Harmonic $i$ | $E_i$ (V/m) | $H_i$ (A/m) | $f_i$ (Hz) | $t_i$ (h) | $Q_i$ (W/m$^2$) |
|---|---|---|---|---|---|
| 1 | 200 | 0.30 | 50 | 1.5 | 60.0 |
| 2 | 100 | 0.20 | 150 | 1.0 | 20.0 |
| 3 | 50 | 0.10 | 350 | 0.5 | 5.0 |
| Total | | | | | $Q_\Sigma$=85.0 |

*Note:* Daily dose: D = 405000 J/m$^2$; Specific daily dose: $D_s$ = 10222 J/kg.

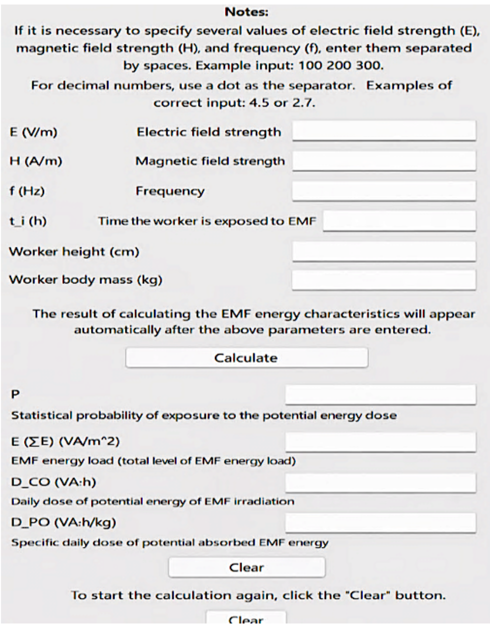


Figure 1: EMF energy characteristics calculator.

Compared with the first demonstration case, Case 2 illustrates how increased field levels and exposure duration lead to higher aggregated indicators $Q_\Sigma$, $D$, and $D_s$, which are summarized in Table 3. This confirms that the tool is suitable for comparative assessment across scenarios.

Figure 1 shows the main interface of the calculator, including fields for harmonic-component inputs and anthropometric parameters, as well as the output block for $Q_i$, $Q_\Sigma$, $D$, and $D_s$. The interface is designed for routine occupational safety use and supports rapid scenario comparison by editing $t_i$ and field levels.

The software tool computes energy-based EMF indicators for harmonic-component inputs in the frequency range from 25 Hz to 1 kHz — chosen because it covers the main harmonic components present in power systems and traction networks, which are the primary sources of occupational EMF exposure in electrical personnel — and provides aggregated outputs across components. The results can be used for subsequent comparison with applicable occupational exposure criteria and for supporting mitigation decisions.

# 4 DISCUSSION

The proposed energy-based indicators provide an additional perspective for occupational EMF assessment by combining harmonic-component exposure data with exposure duration and anthropometric parameters [13]-[17]. This supports routine workplace safety evaluation and decision-making. In workplace practice, additional attention may be required for employees with active implantable medical devices; the assessment workflow can be adapted to such cases according to established approaches [18].

Unlike conventional EMF calculators that focus mainly on field strength values, the developed tool automates the computation of energy-based indicators across multiple harmonic components and includes input validation to ensure consistent datasets.

Use with exposure criteria. In practical occupational safety workflow, the computed indicators can be used as intermediate quantitative outputs: first, workplace measurements provide harmonic-component RMS values of $E_i$ and $H_i$ and exposure durations $t_i$; second, the tool aggregates component-wise contributions into $Q_\Sigma$ and dose-related indicators $D$ and $D_s$; third, the resulting indicators may be compared with the selected regulatory or corporate criteria, and mitigation measures can be planned if the criteria are exceeded (e.g., task rotation, reduced exposure time, engineering controls).

Sensitivity of the indicators. From Eqs. (3)-(7), the indicators scale linearly with field levels and exposure duration. Specifically, doubling $E_i$ or $H_i$ doubles $Q_i$ and proportionally increases $Q_\Sigma$ and $D$. Similarly, increasing $t_i$ directly increases $D$. The specific dose $D_s$ additionally depends on anthropometric parameters through $S$ and $m$, enabling comparison of scenarios for personnel with different body characteristics.

In addition to workplace assessment, the proposed calculator can be used as a training tool to develop practical competencies in occupational EMF safety and decision-making skills for engineering students and technical specialists [19], [20].

The current version focuses on calculation and reporting. Future work may include automated comparison with applicable exposure limits and integration of mitigation-measure recommendations depending on workplace scenarios.

# 5 CONCLUSIONS

This paper presented a C# (Windows Forms) software tool for automated calculation of energy-based EMF indicators under harmonic-component exposure. The tool supports structured input of electric and magnetic field strengths, frequencies, and exposure durations, together with anthropometric parameters, and provides computed outputs through a graphical user interface. The implemented workflow includes input parsing, numeric-format handling, and consistency checks for harmonic-component lists, which reduces the risk of manual calculation errors and improves reproducibility of workplace assessments.

Based on the mathematical model described in the paper, the application computes the energy load $Q_i$ for each harmonic component, the total energy load $Q_\Sigma$, the daily dose of potential EMF exposure energy $D$, and the specific daily dose of potential absorbed EMF energy $D_s$. A demonstration case and verification against an independent spreadsheet implementation confirmed agreement within rounding error, indicating that the computations are implemented correctly. In practical occupational safety tasks, the proposed indicators can be used to standardize reporting, compare exposure scenarios across workplaces, and support prioritization of mitigation measures (e.g., organizational controls and time management).

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