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Development of a Computational Interface for the Thermal Behavior Analysis of Metallic Plates Using the Finite Volume Method

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Abstract: This paper presents the design and implementation of a user-friendly interface for a computational code developed to analyze the thermal behavior of metallic plates using the Finite Volume Method (FVM). The study focuses on the discretization of the heat conduction equation and the creation of an interface that simplifies parameter input and enhances visualization of simulation results. Developed with Visual Basic software, the interface is capable of handling 256 boundary condition cases for two-dimensional simulations and 1296 cases for three-dimensional simulations, providing flexibility in modeling complex thermal problems. It also incorporates an automatic overheating alert, which is activated if the maximum simulated temperature exceeds the melting point of the selected material. Validation was conducted through comparison with Ansys simulations and experimental measurements, confirming the reliability, accuracy, and applicability of the interface. This work offers a versatile and effective solution for thermal analysis in both research and industrial contexts.

Keywords: Thermal analysis, Heat transfer, Interface conception, Numerical simulation.

Introduction

In the field of thermal engineering, numerical simulation tools are essential for predicting heat transfer behavior under various physical and boundary conditions. However, the complexity of numerical models and the need to master specific programming languages often limit their accessibility to non-specialists (Patankar, 1980; Versteeg & Malalasekera, 2007; Incropera et al., 2017). To overcome this limitation, a computational code based on the Finite Volume Method (FVM) was developed to solve the heat conduction equation in metallic plates, following approaches similar to those described by Bejan and Kraus (2003) and Wirtz and Stasiek (2012). The developed code can simulate both steady-state and transient regimes in two- and three-dimensional domains, accounting for various boundary conditions and material properties. To enhance usability and improve simulation efficiency, a graphical user interface (GUI) was subsequently designed using Visual Basic within the Visual Studio Express environment. Inspired by pedagogical principles proposed by Cengel and Ghajar (2020) and Sharma et al. (2019), the interface enables users to define simulation parameters, manage geometry and boundary conditions, and visualize results intuitively—without requiring advanced programming knowledge (Chapra & Canale, 2015; Holman, 2010).

The accuracy and reliability of the numerical approach were verified by comparing results with experimental measurements performed in our laboratory and with numerical simulations conducted using ANSYS Fluent (ANSYS, 2022; Yıldız & Yılmaz, 2017 ; Ahamed et al., 2020). While commercial software offers advanced features, the tool presented here distinguishes itself by its simplicity, flexibility, and seamless integration with a validated FVM code.

It allows complete customization of geometry, boundary conditions, and material properties, while incorporating safety mechanisms such as automatic parameter verification and overheating alerts. These characteristics, combined with direct experimental validation, make the tool particularly suitable for educational use, research applications, and specific industrial studies where commercial solutions may be too complex, costly, or rigid. Consequently, this two-step development—combining an in-house computational code with a user-friendly interface—provides an innovative, accessible, and reliable platform for thermal simulations of metallic plates, contributing a valuable alternative to existing commercial and academic tools (Basha et al., 2021 ; Zhang et al., 2019).

Methodology and Interface Design

The methodology of this work is based on a two-step approach: first, the development of a reliable computational code using the Finite Volume Method (FVM) for thermal analysis of metallic plates; second, the creation of a user-friendly graphical interface to facilitate the application of the code for both 2D and 3D simulations. The methodology is structured around the following key aspects :

Input and Parameter Management

The developped interface enables users to run thermal simulations without directly interacting with the underlying computational code. It simplifies the process by automating data input, execution, and result visualization, making the simulation more accessible and efficient. This interface is designed with a modular structure, allowing easy integration of new materials, boundary condition types, or visualization features. Its flexibility enables use in various educational and industrial applications, from basic thermal studies to more complex research scenarios. This tool allows users to define all necessary simulation parameters in a clear and organized manner for the 2D or the 3D cases (Figure 1). These include:

- Simulation type : steady state or transient conditions
- Geometric parameters and Mesh.
- Boundary conditions.
- Material properties.

This structured parameter management ensures that all necessary information is provided before the simulation begins, reducing the risk of errors and improving reproducibility.

Simulation Type

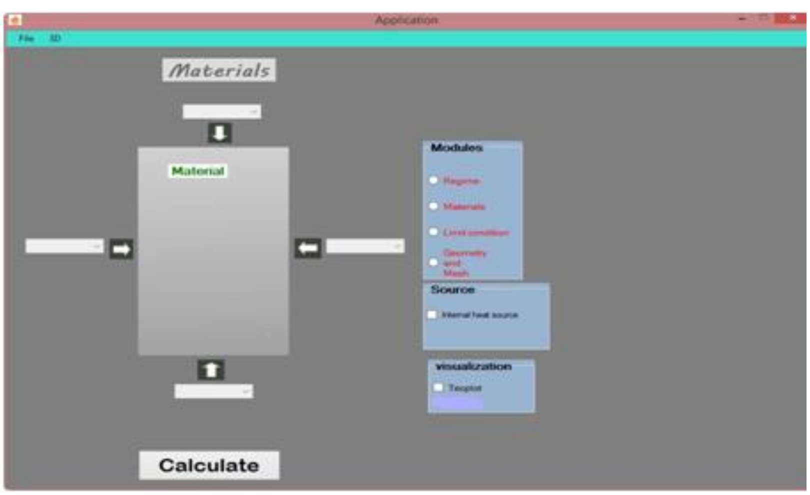

Figure 1. Input panel of the interface showing parameter management.

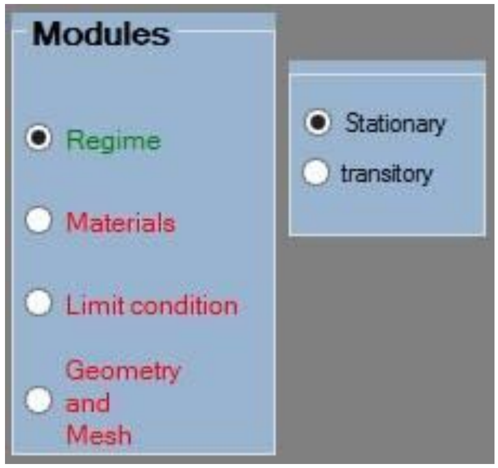

Figure 2. Selection of thermal regime : steady state or transient conditions.

The interface supports both steady-state and transient thermal analysis, with relevant parameters such as simulation duration and time step for transient cases (Figure 2). In the steady-state mode, the program computes the fixed temperature distribution across the plate once equilibrium is reached. This option is mainly used to analyze heat transfer in metallic plates subjected to continuous heat flux or constant boundary temperatures. The transient mode allows the study of temperature evolution over time under variable thermal conditions. Users can define the total simulation duration and time-step directly through the interface. The program automatically manages data saving and graphical visualization at each interval, enabling real-time observation of thermal changes. Both modes are available in 2D and 3D, offering flexibility to investigate steady or time-dependent temperature fields under various boundary and material configurations.

Geometric Parameters and Mesh

The geometry module enables users to define the physical dimensions of the metallic plate, including length, width, and thickness (Figure 3). The meshing parameters are defined independently along each spatial direction, offering control over grid density and spatial resolution. The mesh is structured, allowing accurate discretization of the conduction domain while ensuring numerical stability. Users can easily adjust the number of nodes in each direction to balance computational cost and accuracy. The developed interface also performs automatic mesh quality checks to detect excessive aspect ratios or non-uniform spacing that could compromise solution precision.

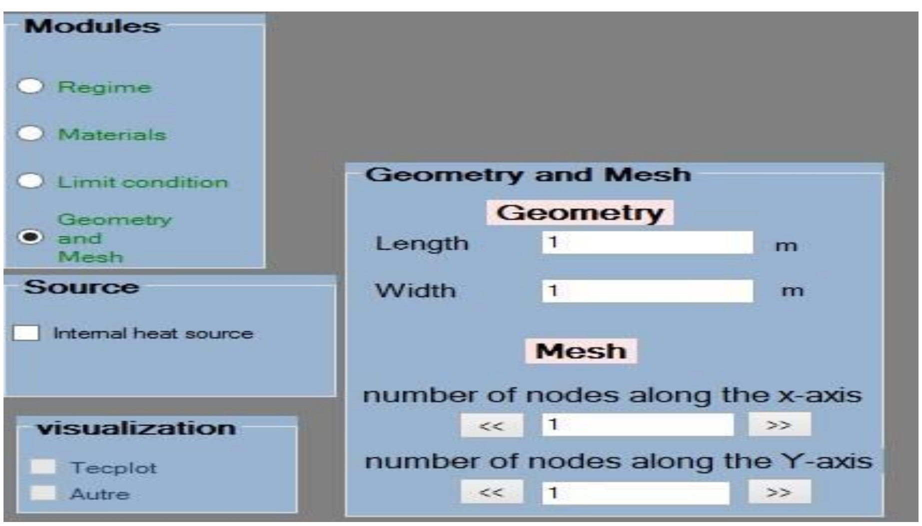

Figure 3. Geometry and mesh selection panel with multiple options for each surface of the plate.

Boundary Conditions

The interface provides extensive flexibility for defining boundary conditions on each plate surface (Figure 4). Users can assign:

- Imposed temperature (Dirichlet condition) for constant or variable temperature boundaries.
- Specified heat flux (Neumann condition) for controlled energy input or loss.
- Convective boundary condition (Robin condition), incorporating fluid temperature and convective heat transfer coefficient, enabling the study of forced or natural convection scenarios.
- Perfect insulation, corresponding to zero heat flux.

Each surface can be assigned independently, allowing the modeling of asymmetric or mixed thermal environments. The system automatically adjusts the computational formulation according to the selected conditions, ensuring physical consistency and numerical robustness.

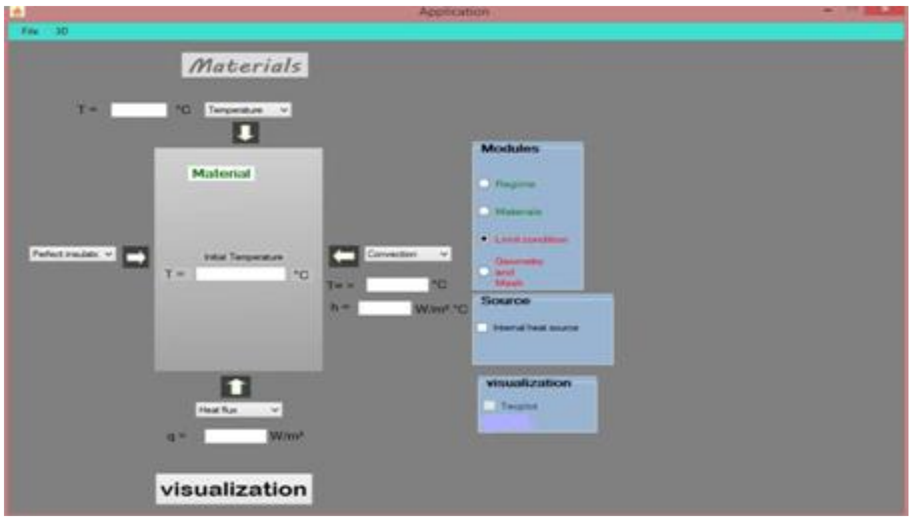

Figure 4. Boundary condition selection panel with multiple options for each surface of the plate.

Material Properties

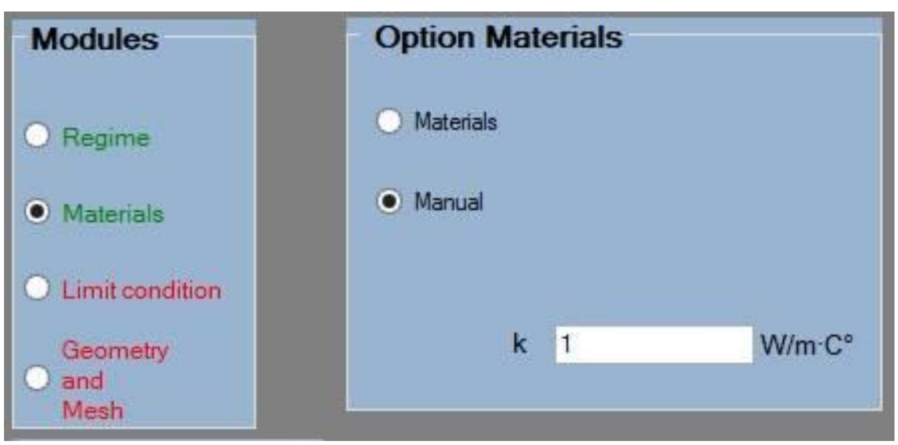

Figure 5. Manual selection of material properties under steady state regime.

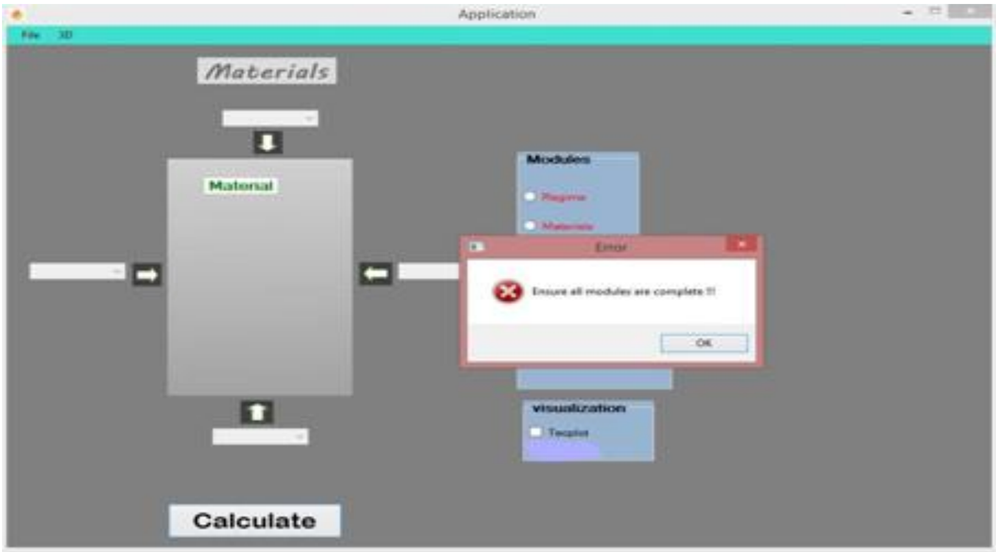

Figure 6. Example of parameter verification alerts triggered during a transient simulation.

A central feature of the interface is the material property database, which includes commonly used metallic materials such as aluminum, copper, steel, and titanium. Each material entry contains default thermal conductivity (k), density (ρ), and specific heat capacity (C_p) values based on standard references. However, users may also define these properties manually to simulate non-standard alloys or composite materials (Figure5). In steady-state simulations, the material's thermal conductivity predominantly governs the spatial temperature distribution, while in transient simulations, density and specific heat capacity determine the rate of temperature evolution.

Safety and Error Management

Reliability is a primary design criterion of the proposed tool. To this end, the interface includes multiple verification and alert systems that operate before and during simulation execution:

- Parameter verification alerts prevent execution when mandatory inputs such as boundary conditions, geometric parameters, or time-step values are missing or physically inconsistent (Figure 6).
- Overheating alerts notify users if the maximum simulated temperature exceeds the melting point of the chosen material, preventing nonphysical results and highlighting potential design flaws.
- Boundary consistency checks ensure that all surfaces are assigned valid thermal conditions, reducing user-induced numerical errors.

These built-in safety features increase user confidence, particularly for beginners or students, and contribute to ensuring the reproducibility and accuracy of all simulation runs.

Visualization and Results Interpretation

Once the computation is completed, the interface provides two main modes of result visualization:

- Numerical display of nodal temperatures, which allows precise inspection of thermal values at each point.
- Graphical representation, using integrated plotting tools to generate 2D or 3D temperature maps, facilitating intuitive understanding of the thermal distribution (Figure 7).

In addition, users can export results for further analysis or reporting.

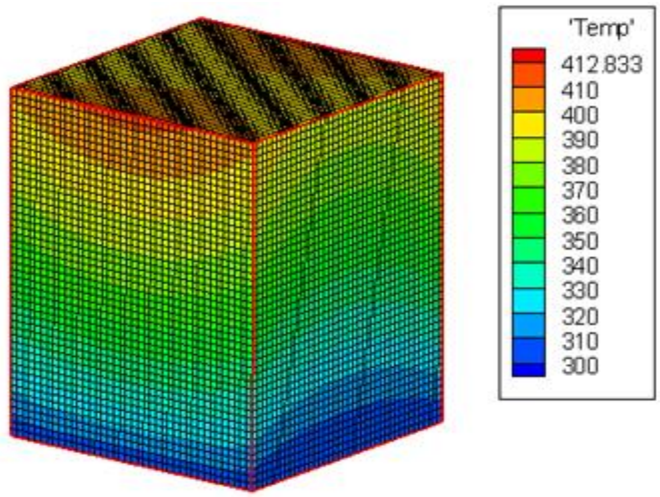

Figure 7. 3D Graphical representation of the temperature showing thermal gradients across the plate depth (Tecplot visualisation).

Results and Discussion

Simulations were conducted on metallic plates with uniform geometry to evaluate temperature distributions under various boundary conditions. The interface allows users to visualize the temperature field at each node either numerically or graphically. As expected, higher temperatures are observed near heat sources and decrease toward insulated or convective boundaries, demonstrating the correct implementation of heat transfer physics.

Validation with ANSYS Fluent

To assess the accuracy of the developed FVM code and interface, the same 2D configurations were simulated using ANSYS Fluent, a widely recognized commercial CFD software. The comparison indicates excellent agreement between the numerical results from the developed interface and ANSYS simulations, with deviations not exceeding 2%. This confirms the robustness and correctness of the numerical implementation (Figure 8 and Figure 9).

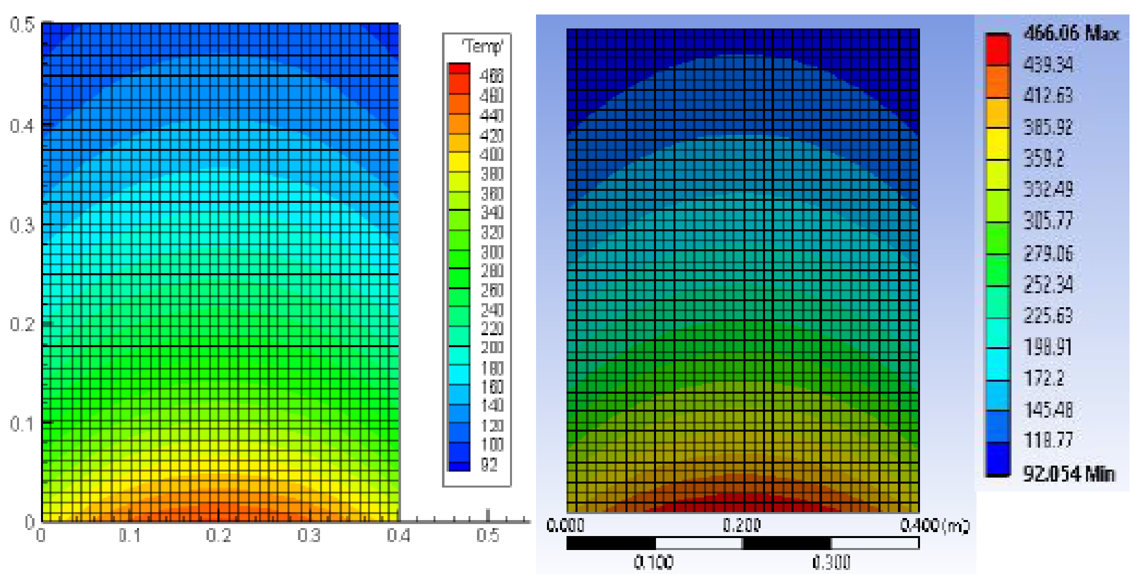

Figure 8. Comparison of 2D temperature distributions obtained from the developed interface and ANSYS Fluent.

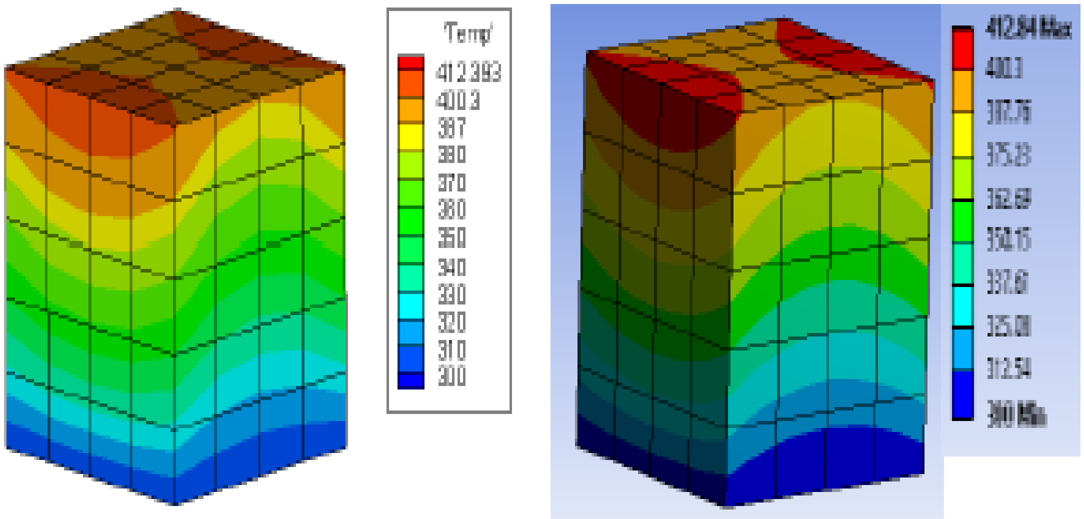

Figure 9. Comparison of 3D temperature distributions obtained from the developed interface and ANSYS Fluent.

Validation with Experimental Measurements

In addition to software validation, experimental measurements were performed on solid metallic plates under controlled laboratory conditions. To collect the data of the sensed temperatures, circuits were used based on the Arduino programmable board or the Pic 16F8777A microcontroller programmed by the MicroC and Proteus software. Temperature profiles obtained experimentally were compared with both 2D and 3D numerical simulations. The results demonstrate excellent agreement. Minor differences are attributed to experimental uncertainties such as thermal contact resistance and ambient temperature variations.

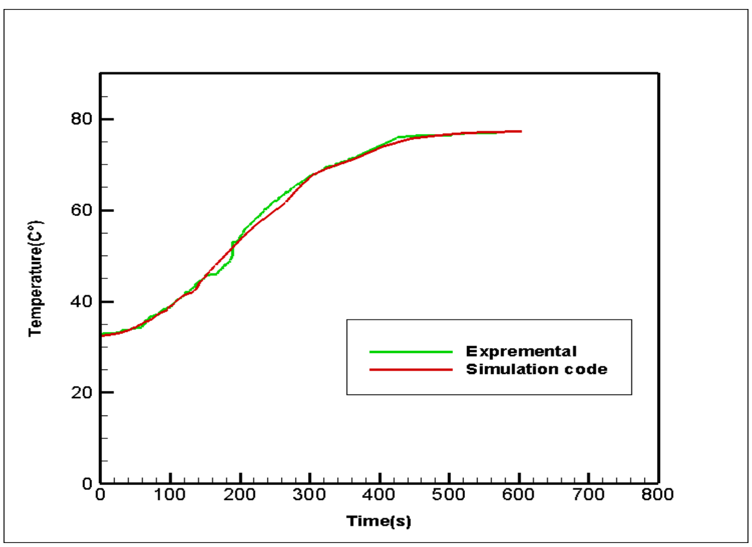

Figure 10. Comparison of 2D numerical simulations with experimental measurements for a solid metallic plate.

Discussion

The discussion of the obtained results can be divided into two main parts: the interface design (Figures 1–7) and the validation of the numerical model (Figures 8–10).

Interface Design and Functionality (Figures 1–7)

The first series of figures illustrates the progressive construction of the interface and its main features. As shown in Figures 1 and 2, the panels for parameter management and simulation-type selection allow the user to define geometric, material, and boundary parameters for both steady and transient regimes. This structure facilitates data entry and reduces the risk of input errors. Figure 3 presents the geometry and meshing module, which enables control over grid resolution and uniformity in each spatial direction. The automatic verification of mesh quality helps maintain numerical stability.

Figures 4 and 5 show that boundary conditions and material properties can be assigned independently to each surface, which increases modeling flexibility. The material database includes common metals but can also be adjusted for other alloys, making the tool adaptable to different studies. Figure 6 demonstrates the inclusion of verification and alert systems that prevent missing or inconsistent parameters and indicate possible overheating. These safety checks improve the reliability of simulations.

Finally, Figure 7 illustrates the visualization module, which provides numerical and graphical representations of temperature fields in two and three dimensions. This visualization assists in interpreting the main heat transfer trends and in verifying the overall consistency of the simulation. One key advantage of the developed code is that it integrates all these functions within a single interface, allowing users to perform complete simulations—from parameter definition to result visualization—without directly manipulating the numerical code. This combination increases efficiency, minimizes user errors, and makes the tool accessible even to non-specialists.

Validation and Interpretation of Results (Figures 8–10)

The numerical results obtained with the developed interface were compared with those from ANSYS Fluent to verify the accuracy of the finite volume implementation. As shown in Figures 8 and 9, the temperature distributions obtained with both methods are in close agreement, with deviations not exceeding 2%. This indicates that the discretization scheme and boundary condition treatment are correctly implemented. Experimental validation, illustrated in Figure 10, shows a good correlation between simulated and measured temperatures. Small differences are mainly due to contact resistance, measurement uncertainties, and minor variations in ambient conditions. Overall, these results confirm that the numerical approach represents the physical behavior of heat conduction with satisfactory accuracy. The influence of boundary conditions, material conductivity, and plate thickness is clearly observed in the simulations. The 3D cases highlight temperature variations through the plate depth that cannot be captured by 2D analysis alone. The interface therefore provides a practical means of examining these effects without requiring manual coding or complex preprocessing. The results show that the interface facilitates the definition of simulation parameters, ensures stable numerical results, and provides accurate predictions consistent with commercial software and experimental data. Its main advantage lies in combining a validated numerical method with an intuitive interface that simplifies and accelerates the entire simulation process.

Conclusion

This work presents the development and implementation of a user-friendly graphical interface for thermal analysis of metallic plates using the Finite Volume Method (FVM). The interface provides an intuitive environment for defining simulation parameters, managing geometry and boundary conditions, and visualizing results in both 2D and 3D. The developed tool has been validated through comparisons with ANSYS Fluent simulations and experimental measurements on solid plates, demonstrating excellent agreement and confirming the accuracy and reliability of the numerical model. The interface further enhances usability by incorporating real-time alerts for missing parameters and overheating, allowing both specialists and non-specialists to perform simulations efficiently and safely. The novelty of this work lies in the integration of a validated FVM computational code with a fully functional, intuitive interface that bridges the gap between advanced numerical simulation and practical experimental validation. This combination provides a versatile tool suitable for educational purposes, research, and preliminary industrial applications, where commercial software may be too complex, expensive, or less flexible.

Future developments may include extending the interface to complex geometries, internal perforations, non-homogeneous materials, and automated meshing, further enhancing its applicability for advanced thermal analysis. Overall, this study demonstrates that a robust, flexible, and validated simulation tool can significantly simplify thermal problem-solving while maintaining accuracy and reliability.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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