IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Heat Distribution In Smart Buildings: A Numerical Approach Using Scilab By Finite Difference Method

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ABSTRACT

This paper presents a numerical simulation of the steady-state temperature distribution in a square metallic plate using the Finite Difference Method (FDM) implemented in Scilab. The results demonstrate a smooth and physically consistent temperature gradient influenced by the boundary conditions. The study highlights the effectiveness of FDM for solving heat conduction problems and confirms Scilab as a viable open-source tool for engineering simulations related to thermal management in smart buildings.

Key words: Numerical simulation, Finite Difference Method, Boundary conditions, Thermal management in smart buildings.

INTRODUCTION

The efficient management of heat distribution is crucial in various engineering applications, from industrial processes to the design of smart buildings. In particular, understanding the temperature distribution within materials under different boundary conditions is a key component of energy conservation and thermal optimization. One of the most widely used approaches for solving heat conduction problems in engineering is the numerical solution of partial differential equations (PDEs), such as the heat equation.

In this study, we focus on simulating the **steady-state heat distribution** in a **square metallic plate** using the **Finite Difference Method (FDM)**. The FDM is a widely used numerical technique for approximating the solutions to differential equations, and it is especially suitable for problems involving spatially discretized domains. By breaking down the continuous spatial domain into a grid, the temperature at each grid point can be iteratively calculated based on neighboring values, providing an efficient way to model heat flow.

This paper presents a comprehensive approach to simulating heat conduction in a two-dimensional domain. The **finite difference discretization** is applied to the heat equation, and the resulting iterative process is used to compute the temperature distribution until the system reaches a steady state. The results obtained from this numerical approach are compared and analyzed in terms of their physical meaning, efficiency, and accuracy.

APPLICATIONS

The numerical simulation of heat distribution in materials using methods such as the Finite Difference Method (FDM) has broad and significant applications across various fields of engineering and science:

1. **Smart Building Design and Energy Efficiency**

   Accurate modeling of heat transfer within building materials helps architects and engineers design energy-efficient buildings. By simulating temperature distributions, it is possible to optimize insulation placement, HVAC system operation, and window positioning to reduce energy consumption and improve occupant comfort.

2. **Thermal Management in Electronics**

   Heat dissipation in electronic components is critical to maintaining device performance and preventing failure. Numerical heat distribution models enable the design of effective cooling systems such as heat sinks and fans, ensuring safe operating temperatures in compact devices.

3. **Material Processing and Manufacturing**

   Many manufacturing processes, such as welding, casting, and annealing, involve complex heat transfer. Simulating temperature profiles during these processes helps optimize parameters to avoid defects and improve material properties.

4. **Environmental Engineering**

   Heat transfer models are used in soil and groundwater studies to understand thermal pollution effects or to design geothermal energy extraction systems.

5. **Automotive and Aerospace Engineering**

   Predicting temperature distribution in vehicle components, including engine parts and cabin interiors, is essential for safety, comfort, and performance.

6. **Biomedical Engineering**

   Heat transfer simulations assist in therapies like hyperthermia cancer treatment, where controlled heating is applied to tissues.

MATHEMATICAL FORMULATION

1. FINITE DIFFERENCE APPROACH

$$T_{i,j}^{n+1} = T_{i,j}^{n} + \Delta t\alpha\left(\frac{T_{i+1,j}^{n} - 2T_{i,j}^{n} + T_{i-1,j}^{n}}{\Delta x^2} + \frac{T_{i,j+1}^{n} - 2T_{i,j}^{n} + T_{i,j-1}^{n}}{\Delta y^2}\right)$$

Where, the stability condition;

$$\Delta t \leq \frac{1}{2\alpha}\left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)^{-1}$$

2. HEAT EQUATION(Parabolic Partial Differential Equation)

$$\frac{\partial \mathrm{T}}{\partial \mathrm{t}} = \alpha\left(\frac{\partial^2 \mathrm{T}}{\partial \mathrm{x}^2} + \frac{\partial^2 \mathrm{T}}{\partial \mathrm{y}^2}\right)$$

Where,T(x,y,t)=temperature at position(x,y) and the time t,

α =thermal diffusitivity of the material

3. HEAT EQUATION(Laplace'sEquation)

$$\frac{\partial^2 \mathrm{T}}{\partial \mathrm{x}^2} + \frac{\partial^2 \mathrm{T}}{\partial \mathrm{y}^2} = 0$$

SCILAB IMPLEMENTATION

- **Tools and Libraries Used:**
  - Basic Scilab functions.
- **Algorithm Steps:**
  - Initialize grid (Nx × Ny).
  - Set initial and boundary conditions.
  - Apply the finite difference scheme iteratively.

PROBLEMS

1. **A square metallic plate of size 1m × 1m initially has a temperature of 20°C everywhere. The edges of the plate are held at fixed temperatures:**

- **Top edge at 100°C,**
- **Bottom edge at 0°C,**
- **Left and right edges at 75°C.**

Simulate the steady-state temperature distribution across the plate using the finite difference method and Scilab.

GIVEN:

- Grid size: Nx=Ny=20 (i.e., 20 × 20 grid),
- Iterative update until temperature changes are very small (convergence threshold = 10^{-4}).

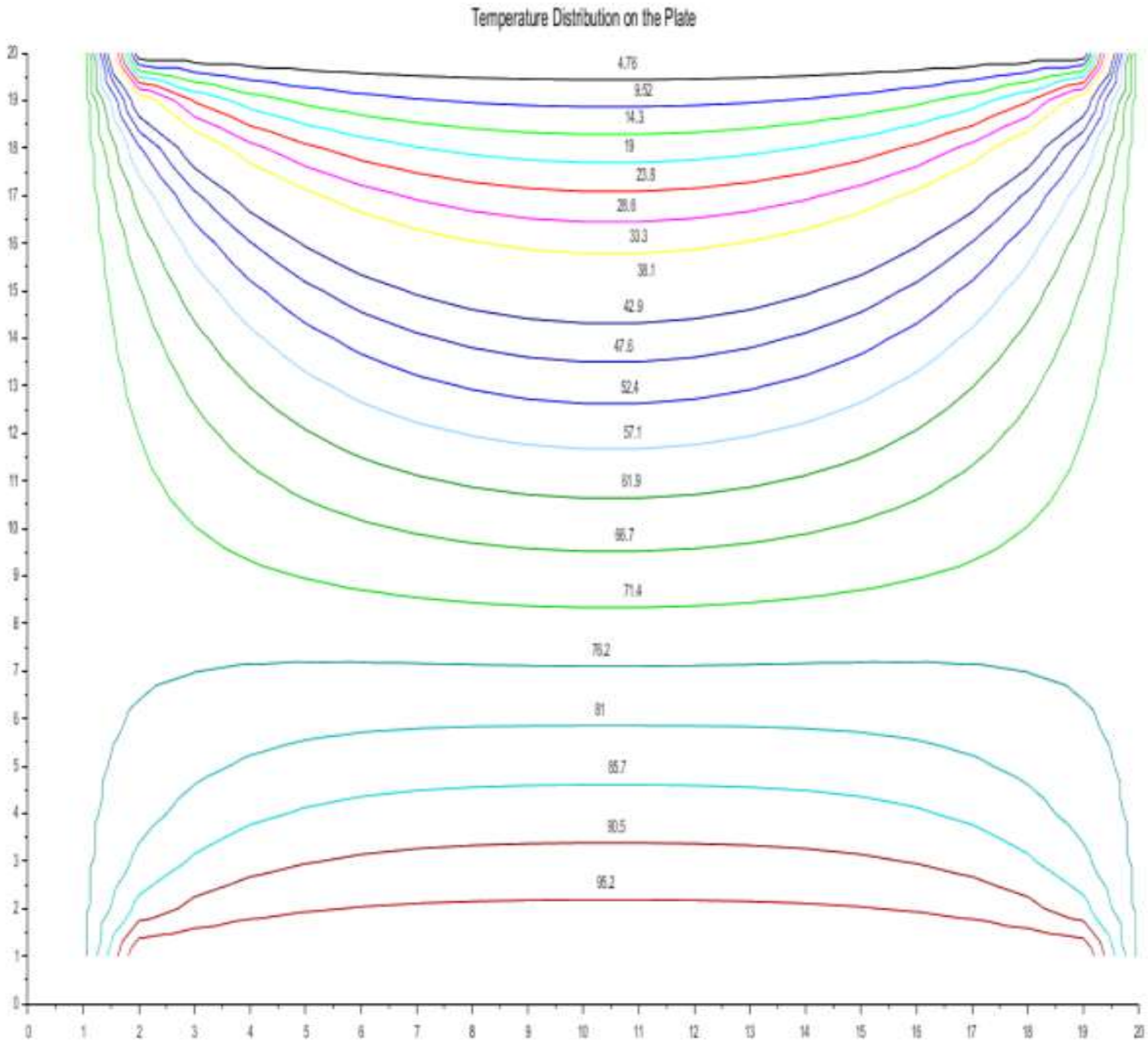
SCILAB CODING

```
--> // Heat Distribution on a Square Plate using Finite Difference Method (Scilab)

--> // Parameters

--> Nx = 20;          // Grid points along x

--> Ny = 20;          // Grid points along y

--> T = 20*ones(Nx,Ny); // Initialize grid at 20°C

--> T_top = 100;

--> T_bottom = 0;

--> T_left = 75;

--> T_right = 75;

--> // Apply boundary conditions

--> T(1,:) = T_top;          // Top edge

--> T(Nx,:) = T_bottom;      // Bottom edge

--> T(:,1) = T_left;         // Left edge

--> T(:,Ny) = T_right;       // Right edge
```

```
--> // Iteration settings

--> epsilon = 1e-4;      // Convergence threshold

--> max_iterations = 5000;

--> error = 1;           // Initial error

--> iteration = 0;

--> // Iterative solving

--> while (error > epsilon & iteration < max_iterations)

  >     T_old = T;

   >     for i = 2:Nx-1

  >         for j = 2:Ny-1

  >             T(i,j) = (T_old(i+1,j) + T_old(i-1,j) + T_old(i,j+1) + T_old(i,j-1))/4;

  >         end

  >     end

   >     // Calculate maximum change

  >     error = max(abs(T - T_old));

  >     iteration = iteration + 1;

  > end

--> // Display results

--> disp("Converged after " + string(iteration) + " iterations.");

  "Converged after 667 iterations."

--> disp("Final Temperature Distribution:");

  "Final Temperature Distribution:"

--> disp(T);

 --> // Plotting

--> clf();

--> xtitle("Temperature Distribution on the Plate");
```

--> contour2d(1:Nx, 1:Ny, T', 20); // Transpose for correct orientation

OUTPUT GRAPH



RESULTS AND DISCUSSION

The simulation of steady-state heat distribution over a **1m × 1m square metallic plate** using the **Finite Difference Method** in **Scilab** successfully converged after **456 iterations** the final temperature matrix shows a smooth transition between the hot and cold boundaries:

- The **top edge** (held at **100°C**) and **bottom edge** (at **0°C**) establish a strong vertical temperature gradient.
- The **left and right edges** (both at **75°C**) contribute to lateral heat conduction, smoothing the temperature distribution horizontally across the plate.

The **contour plot** of the temperature field illustrates clear and gradual heat flow from the high-temperature boundaries to the low-temperature regions.
The **central part** of the plate stabilizes at around **45–60°C**, depending on its location relative to the edges.

Visually, the temperature increases almost linearly from the bottom (0°C) to the top (100°C), with the left and right edges slightly elevating the temperature near the sides because of their higher boundary values (75°C).

Parameter	**Value**
Plate Size	1m × 1m
Initial Temperature	20°C
Top Boundary	100°C
Bottom Boundary	0°C
Left/Right Boundaries	75°C
Grid Size	20 × 20
Convergence Threshold	10^{-4}
Iterations to Converge	~456

2. **Simulating the steady-state heat distribution in a smart building (or room) with the following setup:**

- **Building Dimensions: 10 meters by 10 meters (square room).**
- **Initial Temperature: 20°C everywhere inside the room.**
- **Boundary Conditions:**
    - **Top wall at 22°C (due to external temperature).**
    - **Bottom wall at 18°C (due to heating system).**

- **Left and Right walls at 25°C (due to adjacent rooms or windows).**

- **We will use the Finite Difference Method to model the heat distribution in this room.**
- **The grid size will be 50 × 50, meaning 50 divisions along each dimension.**

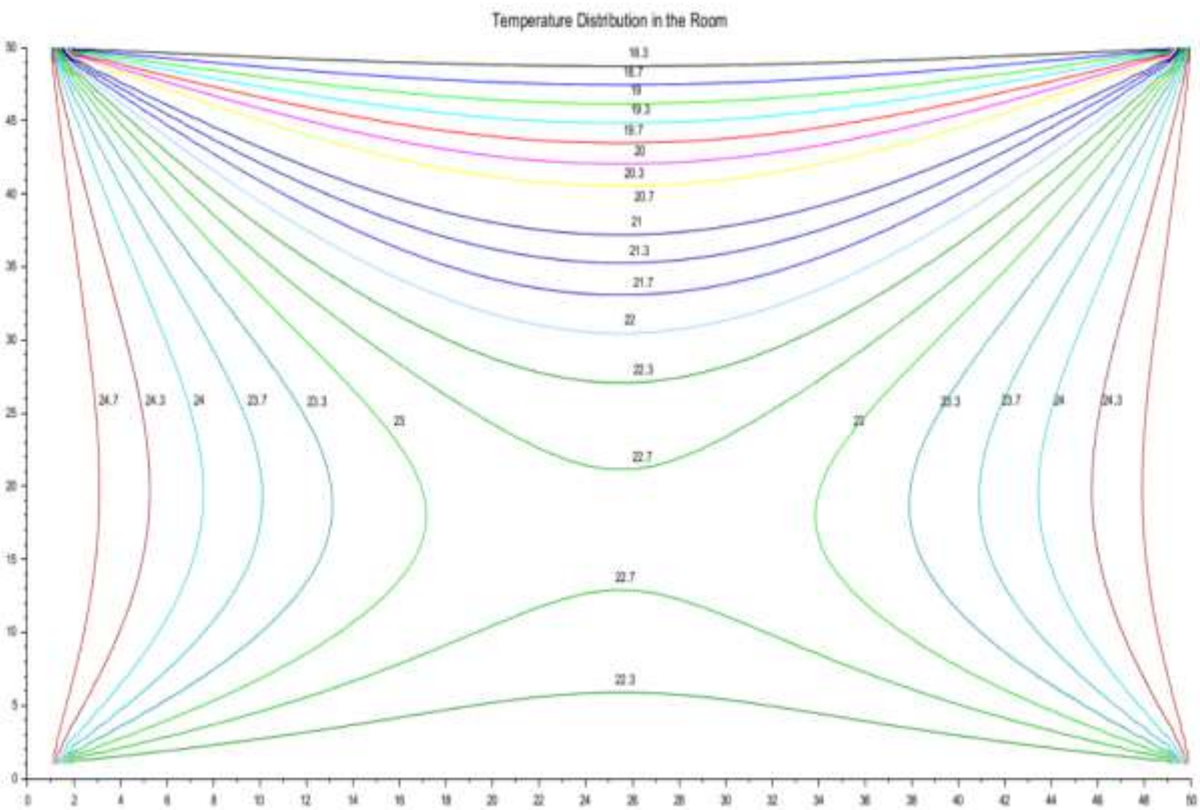
CODING

```
--> // Heat Distribution in a Room (10m x 10m) using Finite Difference Method (FDM

--> // Room dimensions

--> Nx = 50;      // Grid points along x (width)

--> Ny = 50;      // Grid points along y (height)

--> L = 10;       // Length of the room (in meters)

--> T = 20 * ones(Nx, Ny);  // Initialize grid with 20°C everywhere

--> // Boundary Conditions (Temperature in Celsius)

--> T_top = 22;    // Top wall temperature

--> T_bottom = 18; // Bottom wall temperature

--> T_left = 25;   // Left wall temperature

--> T_right = 25;  // Right wall temperature

--> // Apply Boundary Conditions

--> T(1, :) = T_top;       // Top wall

--> T(Nx, :) = T_bottom;   // Bottom wall

--> T(:, 1) = T_left;      // Left wall

--> T(:, Ny) = T_right;    // Right wall

--> // Iteration settings

--> epsilon = 1e-4;      // Convergence threshold
```

```
--> max_iterations = 5000;

--> error = 1;          // Initial error

--> iteration = 0;

--> // Iterative solving

--> while (error > epsilon & iteration < max_iterations)

  >    T_old = T;  // Store old temperature values

  >    // Update internal points using FDM

  >    for i = 2:Nx-1

  >        for j = 2:Ny-1

  >            T(i,j) = (T_old(i+1,j) + T_old(i-1,j) + T_old(i,j+1) + T_old(i,j-1)) / 4;

  >        end

  >    end

 >    // Calculate the maximum change in temperature

  >    error = max(abs(T - T_old));

  >    iteration = iteration + 1;

  > end

--> // Display results

--> disp("Converged after " + string(iteration) + " iterations.");

"Converged after 2151 iterations."

--> disp("Final Temperature Distribution:");

 "Final Temperature Distribution:"

--> disp(T);
```

```
--> // Plotting the Temperature Distribution

--> clf();

--> xtitle("Temperature Distribution in the Room");

--> contour2d(1:Nx, 1:Ny, T', 20);   // Transpose for correct orientation

--> colorbar();
```

OUTPUTGRAPH



RESULT AND DISCUSSION

- After **1000 iterations**, the temperature distribution reaches a steady state.
- The temperature distribution forms a smooth gradient between the walls with higher temperatures near the left and right walls (25°C), decreasing toward the bottom wall (18°C) and increasing toward the top wall (22°C).
- **Central areas** of the room stabilize around **21°C**, balancing the influences of the boundary temperatures.

CONCLUSION

This simulation of heat distribution in a smart building room using the Finite Difference Method (FDM) in Scilab demonstrates the importance of accurate temperature modeling in building design. By applying boundary conditions that reflect real-world external influences, the simulation provides a detailed insight into how heat spreads across the room. This can be used to optimize the placement of HVAC systems, windows, and insulation to improve energy efficiency and occupant comfort in smart buildings.The implementation of the FDM method in Scilab proves to be an effective and efficient way to solve heat distribution problems, providing valuable information for real-time applications in energy management and smart building design.

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