EMT212 PROJECT 1 SEM II 2019/2020

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DATE OF SUBMISSION: 12 JUNE 2020

Table of Contents

Problems Description

The problem given is an industrial cooling system is used to provide cold air within the working area. A typical design of a cooling duct is of rectangular shape. As illustrated in Figure 1, the cross section of the cooling duct pass through a brick wall is shown. The temperature distribution of the brick wall measuring 7 units by 7 units is governed by:

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

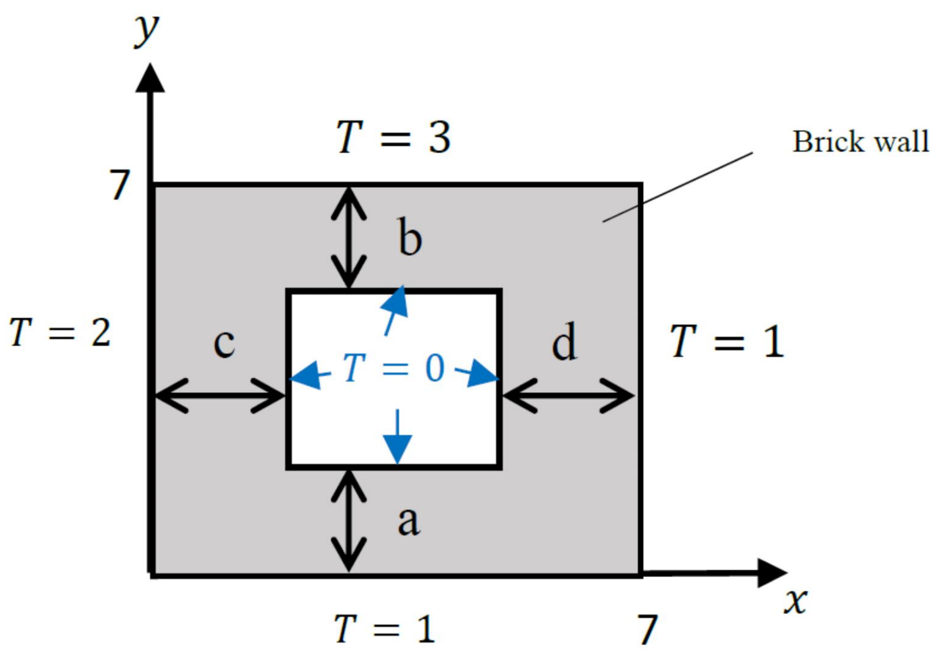

Figure 1: Cross section of a brick wall with cooling duct inside the wall.

Geometric Parameters

Individual students are assigned to different geometric parameters. The spacing a, b, c and d are different from each student. For mine,

$$a = 3$$

$$b = 2$$

$$c = 4$$

$$d = 2$$

Boundary Conditions

The heat conduction problem is subjected to boundary conditions as illustrated on the Figure 1 which can be summarized as,

$$At\ x = 0\,; T = 2$$

$$At\ x = 7\,; T = 1$$

$$At\ y = 0\,; T = 1$$

$$At\ y = 7\,; T = 3$$

It should be also noted that the cooling duct boundary is subjected to T= 0.

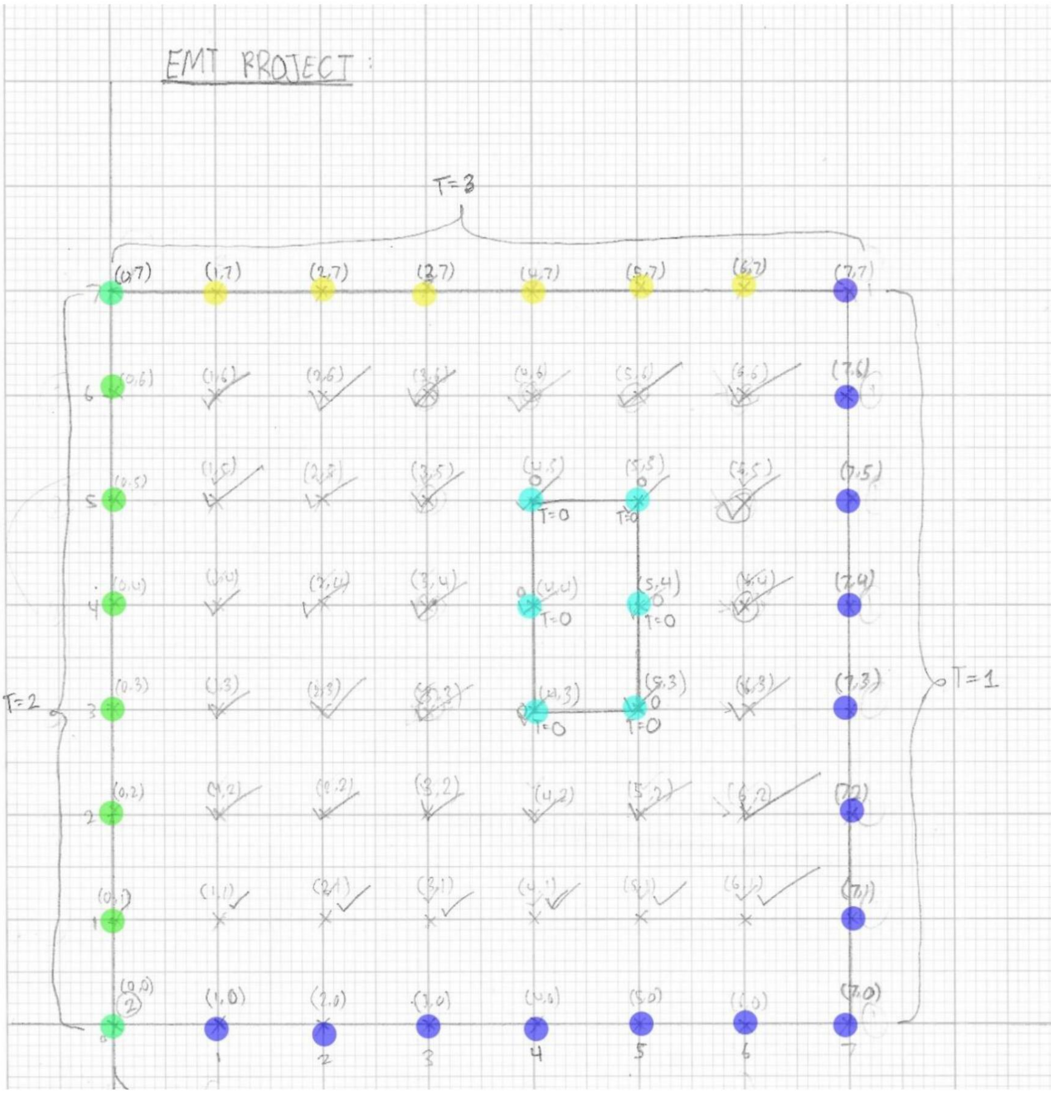

Figure 2: boundary Conditions

The colored point in Figure 2 indicate that it has known value represent the boundary conditions with different color lead to different value. Here are the indicators:

Color	**Temperature, T**
Green	2
Yellow	3
Dark Blue	1
cyan	0

Table 1: Color Indicator

<u>The governing equation</u>

Consider 2D Poisson equation on a square plate:

Transient 2D heat Conduction – T (x,y,t)

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

Where $\alpha = Thermal\ Diffusivity$

From question, the governing equation given is:

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

Which indicate that $\frac{\partial T}{\partial t} = 0$ and $\alpha = 1$.

Calculation

Consider the use of central difference approximation scheme with respect to x and y:

$$\frac{\partial^2 T}{\partial x} = \frac{T_{i+1} - 2T_{i+1} + T_{i-1}}{(\Delta x)^2}$$

$$\frac{\partial^2 T}{\partial y} = \frac{T_{i+1} - 2T_{i+1} + T_{i-1}}{(\Delta y)^2}$$

$$\frac{T_{i+1} - 2T_{i+1} + T_{i-1}}{(\Delta x)^2} + \frac{T_{i+1} - 2T_{i+1} + T_{i-1}}{(\Delta y)^2} = 0$$

To save time and make it less complicated, I assume the spacing of Δx=1 and Δy=1. So here we will have 8 nodes for both x and y directions like shown in figure 2.

Perform the central differencing approximation on the Poisson equation:

$At\ x_1\ and\ y_1$

$$\frac{T_{2,1} - 2T_{1,1} + 2}{(1)^2} + \frac{T_{1,2} - 2T_{1,1} + 1}{(1)^2} = 0$$

Simplified:

$$-4T_{1,1} + T_{1,2} + T_{2,1} = -3$$

Employ the same steps on other nodes:

$At\ x_2\ and\ y_1$

$$T_{1,1} - 4T_{2,1} + T_{2,2} + T_{3,1} = -1$$

$At\ x_3\ and\ y_1$

$$T_{2,1} - 4T_{3,1} + T_{3,2} + T_{4,1} = -1$$

$At\ x_4\ and\ y_1$

$$T_{3,1} - 4T_{4,1} + T_{4,2} + T_{5,1} = -1$$

$At\ x_5\ and\ y_1$

$$T_{4,1} - 4T_{5,1} + T_{5,2} + T_{6,1} = -1$$

$At\ x_6\ and\ y_1$

$$T_{5,1} - 4T_{6,1} + T_{6,2} = -2$$

$At\ x_1\ and\ y_2$

$$T_{1,1} - 4T_{1,2} + T_{1,3} + T_{2,2} = 0$$

$At\ x_2\ and\ y_2$

$$T_{1,2} + T_{2,1} - 4T_{2,2} + T_{2,3} + T_{3,2} = 0$$

$At\ x_3\ and\ y_2$

$$T_{2,2} + T_{3,1} - 4T_{3,2} + T_{3,3} + T_{4,2} = 0$$

$At\ x_4\ and\ y_2$

$$T_{3,2} + T_{4,1} - 4T_{4,2} + T_{5,2} = 0$$

$At\ x_5\ and\ y_2$

$$T_{4,2} + T_{5,1} - 4T_{5,2} + T_{6,2} = 0$$

$At\ x_6\ and\ y_2$

$$T_{5,2} + T_{6,1} - 4T_{6,2} + T_{6,3} = -1$$

$At\ x_1\ and\ y_3$

$$T_{1,2} - 4T_{1,3} + T_{1,4} + T_{2,3} = -2$$

$At\ x_2\ and\ y_3$

$$T_{1,3} + T_{2,2} - 4T_{2,3} + T_{2,4} + T_{3,3} = 0$$

$At\ x_3\ and\ y_3$

$$T_{2,3} + T_{3,2} - 4T_{3,3} + T_{3,4} = 0$$

$At\ x_4\ and\ y_3$

$$T_{4,3} = 0$$

$At\ x_5\ and\ y_3$

$$T_{5,3} = 0$$

$At\ x_6\ and\ y_3$

$$T_{62} - 4T_{6,3} + T_{6,4} = -1$$

$At\ x_1\ and\ y_4$

$$T_{1,3} - 4T_{1,4} + T_{1,5} + T_{2,4} = -2$$

$At\ x_2\ and\ y_4$

$$T_{1,4} + T_{2,3} - 4T_{2,4} + T_{2,5} + T_{3,4} = 0$$

$At\ x_3\ and\ y_4$

$$T_{2,4} + T_{3,3} - 4T_{3,4} + T_{3,5} = 0$$

$At\ x_4\ and\ y_4$

$$T_{4,4} = 0$$

$At\ x_5\ and\ y_4$

$$T_{5,4} = 0$$

$At\ x_6\ and\ y_4$

$$T_{6,3} - 4T_{6,4} + T_{6,5} = -1$$

$At\ x_1\ and\ y_5$

$$T_{1,4} - 4T_{1,5} + T_{1,6} + T_{2,5} = -2$$

$At\ x_2\ and\ y_5$

$$T_{1,5} + T_{2,4} - 4T_{2,5} + T_{2,6} + T_{3,5} = 0$$

$At\ x_3\ and\ y_5$

$$T_{2,5} + T_{3,4} - 4T_{3,5} + T_{3,6} = 0$$

$At\ x_4\ and\ y_5$

$$T_{4,5} = 0$$

$At\ x_5\ and\ y_5$

$$T_{5,5} = 0$$

$At\ x_6\ and\ y_5$

$$T_{6,4} - 4T_{6,5} + T_{6,6} = -1$$

$At\ x_1\ and\ y_6$

$$T_{1,5} - 4T_{1,6} + T_{2,6} = -5$$

$At\ x_2\ and\ y_6$

$$T_{1,6} + T_{2,5} - 4T_{2,6} + T_{3,6} = -3$$

$At\ x_3\ and\ y_6$

$$T_{2,6} + T_{2,5} - 4T_{3,6} + T_{4,6} = -3$$

$At\ x_4\ and\ y_6$

$$T_{3,6} - 4T_{4,6} + T_{5,6} = -3$$

$At\ x_5\ and\ y_6$

$$T_{4,6} - 4T_{4,6} + T_{5,6} = -3$$

$At\ x_6\ and\ y_6$

$$T_{5,6} + T_{6,5} - 4T_{6,6} = -4$$

The Equations Set in Matrix Form

$$
\left(\begin{array}{cccccccccccccccccccccccccccccccccccc}
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\end{array}\right)
\begin{bmatrix} T_{11} \\ T_{21} \\ T_{31} \\ T_{41} \\ T_{51} \\ T_{61} \\ T_{12} \\ T_{22} \\ T_{32} \\ T_{42} \\ T_{52} \\ T_{62} \\ T_{13} \\ T_{23} \\ T_{33} \\ T_{43} \\ T_{53} \\ T_{63} \\ T_{14} \\ T_{24} \\ T_{34} \\ T_{44} \\ T_{54} \\ T_{64} \\ T_{15} \\ T_{25} \\ T_{35} \\ T_{45} \\ T_{55} \\ T_{65} \\ T_{16} \\ T_{26} \\ T_{36} \\ T_{46} \\ T_{56} \\ T_{66} \end{bmatrix}
=
\begin{bmatrix} -3 \\ -1 \\ -1 \\ -1 \\ -1 \\ -2 \\ -2 \\ 0 \\ 0 \\ 0 \\ 0 \\ -1 \\ -2 \\ 0 \\ 0 \\ 0 \\ 0 \\ -1 \\ -2 \\ 0 \\ 0 \\ 0 \\ 0 \\ -1 \\ -2 \\ 0 \\ 0 \\ 0 \\ 0 \\ -1 \\ -5 \\ -3 \\ -3 \\ -3 \\ -3 \\ -4 \end{bmatrix}
$$

Matlab Code

```
%Written by: [MOHAMAD NAZHAN BIN MOHAMAD SHABAERI]
%Student Matric Number: [141935]
%EMT212 PROJECT 1 SEM II 2019/2020

A=[-4 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
1 -4 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 1 -4 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
0 0 1 -4 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0;
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 -4 0 0 0 0 0 1;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 -4 1 0 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 -4 1 0 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 -4 1 0 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 -4 1 0;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 -4 1;
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 -4];


b=[-3; -1; -1; -1; -1; -2; -2; 0; 0; 0; 0; -1; -2; 0; 0; 0; 0; -1; -2; 0; 0;
0; 0; -1; -2; 0;
    0; 0; 0; -1; -5; -3; -3; -3; -3; -4];

t=A\b;

n=8;

x =[linspace(0,7,8); linspace(0,7,8);linspace(0,7,8);linspace(0,7,8);
   linspace(0,7,8); linspace(0,7,8);linspace(0,7,8);linspace(0,7,8)];
```

```
y =[0*ones(1,8); 1*ones(1,8); 2*ones(1,8); 3*ones(1,8); 4*ones(1,8);
    5*ones(1,8); 6*ones(1,8); 7*ones(1,8)];


T=zeros(n);
T(n,1:n)=3;
T(1:n,n)=1;
T(1,2:7)= t(1:1);
T(1,1:n)=1;
T(2,2:7)= t(1:6);
T(3,2:7)= t(7:12);
T(4,2:7)= t(13:18);
T(5,2:7)= t(19:24);
T(6,2:7)= t(25:30);
T(7,2:7)= t(31:36);
T(1:n,1)=2;

contourf (x,y,T)
```

Plot for The Solution

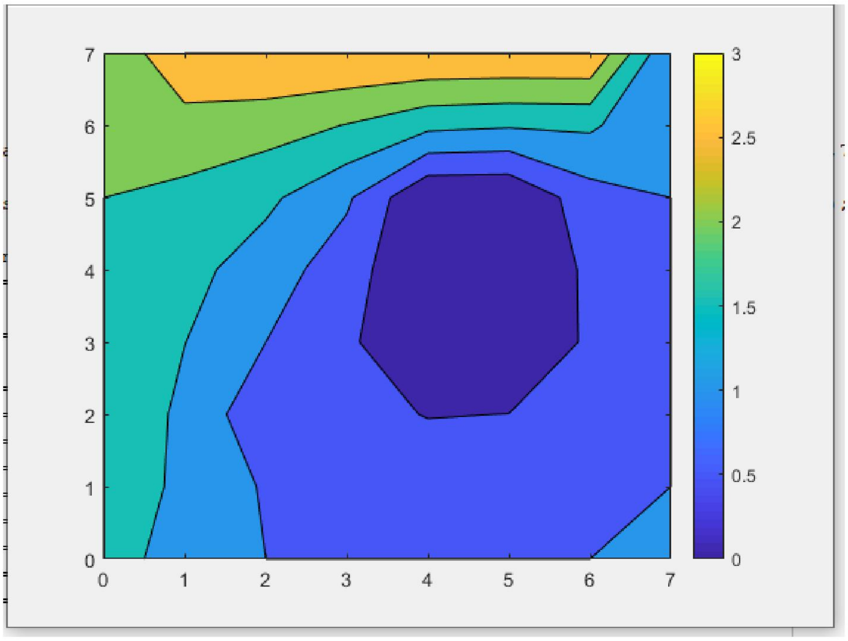

Figure 3: Solution's Plot Contour

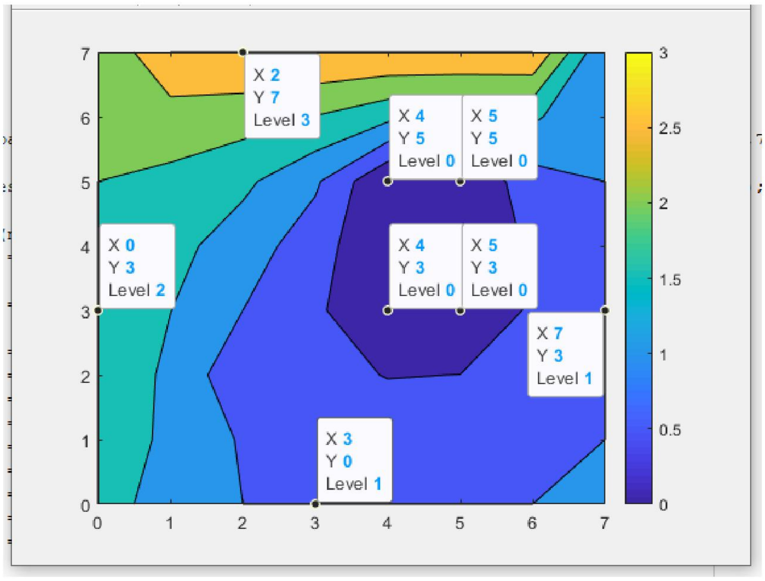

Figure 3.1: Contour Satisfied All The Boundaries

We can see in Figure 3.1 that all the boundary conditions are satisfied.

References

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   http://people.ucalgary.ca/~hugo/WEBPAGES/heat%20transfer/ht_videopages/ht_L1.html#a5

3. 2D Heat Transfer using Matlab [Video]. (2018). Youtube.
   Retrieved from: https://www.youtube.com/watch?v=x47QZxVF1gY&t=196s