Heat Transfer in Cylindrical Building with Various Glass Wall Arrangements

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***Abstract*— This paper presents steady-state temperature distributions of three cylindrical model building, each with different glass wall arrangements. Laplace equation in two-dimensional rectangular coordinate system was used. The temperature distributions were determined by using a finite difference method (FDM) and a finite element method (FEM). The assumptions were that the buildings are closed and the convection and radiation were not considered. Simulation results showed that the different arrangements of glass wall yielded different temperature distributions. With the same total glass area, having small but many number of glasses wall let in less heat comparing to having large but few number of glasses.**

***Keywords*—Heat Transfer, Finite Difference Method, Finite Element Method**

I. Introduction

The temperature in a hot humid climate country such as Thailand is steadily increasing. This is the result of the global warming among other things. In addition, the demand for use of buildings and utilities is also increasing. Thus, the increasing number of building results in the increasing energy consumption. There are scientists and conservationists trying to think of ways to help reduce energy use. One way is to develop better construction material such as roof material, reflective paint, proper insulation, and so on. The other way is to develop a better conceptual ecological design.

Many researchers attempted to simulate and experiment on heat transfer in different types of buildings. In 2005, V. Cheng et.al [1] described the effects that color and thermal mass on indoor temperature. Later, Y. Ungkoon et.al [2] studied microstructure and properties of kinds of concrete walls. Past moments from then on, S. Siriteerakul et.al [3-6] simulated heat diffusion through different types of wall materials, roof tiles, glass wall arrangement patterns in rectangular building, and heat transfer in buildings with different geometrical structures.

The main problem studied in this paper is about heat transfer at steady state of the buildings. We studied cylindrical buildings made from glass and concrete materials. Distribution temperature in three patterns with different glass wall arrangements were computed and illustrated (Fig.3). Our simulation were carried out to compare the interior temperature of the three building patterns. This result can help us design a better energy conserved building.

To simulate, the finite difference method under Crank-Nicolson scheme and the finite element method under Galerkin principle in two dimensional rectangular coordinate system were used. The assumptions made were that the building was a closed space with no convection nor radiation. The temperature considered through the building material is the same and the same amount of material is used. The different we studied is the number of glass wall arrangement in three patterns as in Fig.2.

II. Governing Equation

In this paper, the steady state temperature distributions in the buildings, each with a differently glass arrangement, was solved by using Laplace equation.

The governing equation of steady state heat conduction in two dimensional rectangular coordinate systems can be expressed as:

$$T_{xx} + T_{yy} = 0 \qquad (1)$$

,where T is the temperature at each point.

III. Methodology

To compute and determine the solution, finite difference method and finite element method were used as follows:

Finite Difference Method

Finite difference method has been used by Runge [7] since 1980. This method is a classical numerical method to solve various problems which are in partial differential equations and their domains are not complicated. Later, many researchers applied with computational fluid dynamics problems such as Young and Wheeler [8], Richtmyer and Morton [9], S. Bunditsaovapak and V. Ngamaramvaranggul [10].

For any problem, we start with separating domain by uniform grid and given nodal points shown in Fig.1.

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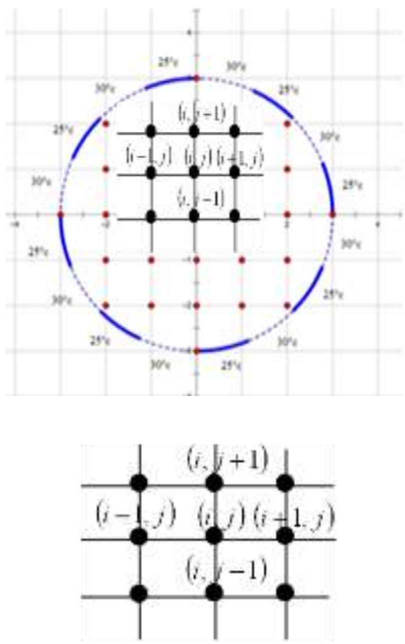


Fig.1 Generating grid points

Simultaneously, the differential equations are using approximate their derivatives by finite difference at any point in domain. There are three schemes to approximate the derivatives as explicit scheme (forward difference), implicit scheme (backward difference) and Crank-Nicolson scheme (central difference). For this heat diffusion equation, the numerical solution was based on Crank-Nicolson scheme.

From Governing equation, the Laplace equation was estimated the derivatives by using Taylor series expansion as follows:

$$\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1,j} - 2T_{i,j} + T_{i-1,y}}{h^2}$$
$$\frac{\partial^2 T}{\partial y^2} = \frac{T_{i,j+1} - 2T_{i,j} + T_{i,j-1}}{k^2} \qquad (2)$$

After substitution and rearrangement, the equation for becomes

$$T_{i+1,j} + T_{i-1,y} - 4T_{i,j} + T_{i,j+1} + T_{i,j-1} = 0 \qquad (3)$$

From the above equation, an equation for each unknown points are obtained. Then, all equations were written in system of linear equations (Ax=b). After that, the system can be solve by direct technique or iterative technique. This study, Wolfram Mathematica was used to find the result of unknown temperature points.

Finite Element Method

Finite element method is a numerical method to solve boundary value problems which the domains are various shapes. This method has been used first in 1965 by Zienkiewicz and Cheung [11]. Then, many researcher developed and applied this method to filament stretching problems for example S. Bunditsaovapak and V. Ngamaramvaranggul [10]. Currently, the finite element method has been used to solve for the solution of complex problems in different field of medical, engineering and science: heat transfer, fluid flow, bridge structure and vibration. Some group attempted create software program to solve the problems. For example, P. Dechaumpai and S.Phongthanapanich created Easy FEM software [12] to solve Laplace problem, which used principle of the finite element method and it is easy to use. On the other hand, our group created software program by using visual C++ studio for solve heat conduction and fluid dynamics problems. This software was created under Galerkin principle. In this study, we employed EasyFEM software to find the results.

IV. Problem Specifications

Given buildings that we consider is a cylinder. After that we reduce their domains to 2-dimension, we obtained new domains in circle shapes.

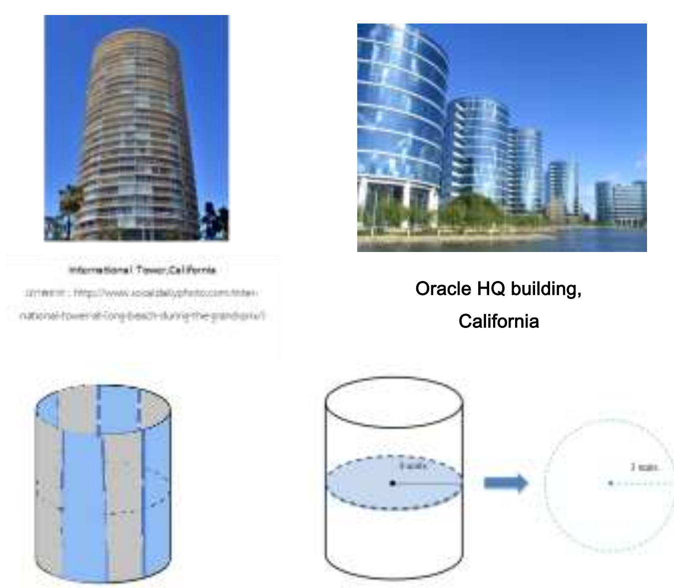


Fig.2 Domains of cylindrical building

To determine the problem, we set radius of each buildings is three units. Then, circumference length is 6π. The assumptions consist of volume of the glass and the cement wall to be the same, the temperature that passes through the glass into the building is 30℃ and the temperature that the cement enters the building 25℃. The problem is divided into 3 patterns as shown in Fig.3. The building patterns were divided into 4 parts, 8 parts, and 16 part, respectively.

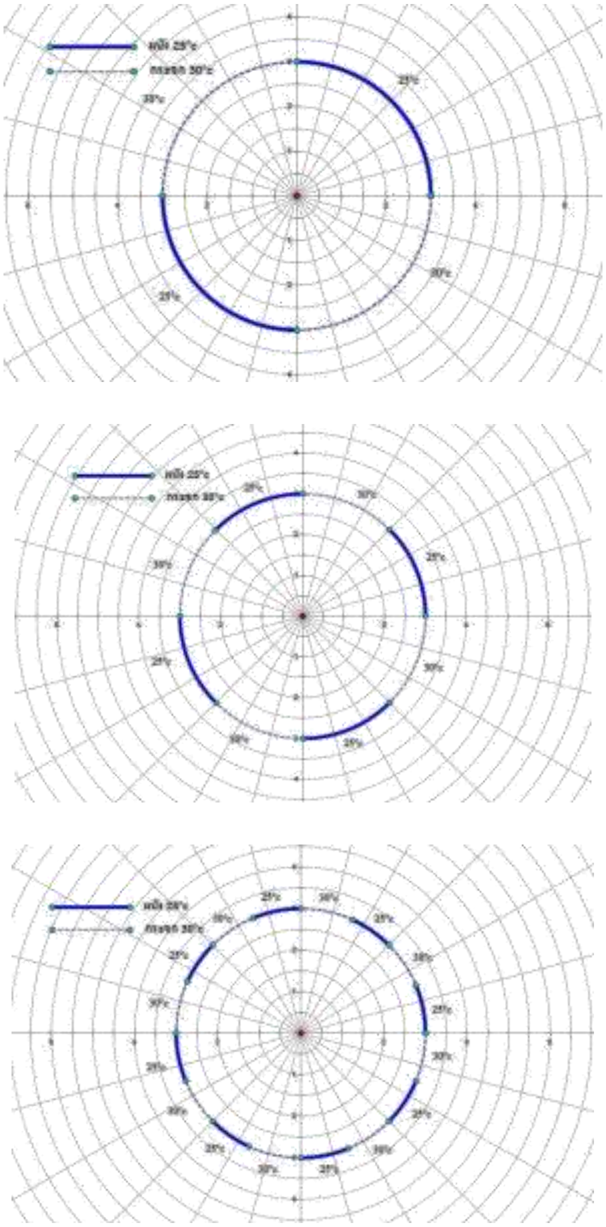


Fig. 3 Domains of this problem

For computation by using finite difference method, the grid points of each domains were generated in order to solve thermal value at the points as shown in fig. 4. All three domains will be considered the same number of points and positions.

For solutions by finite element method, we obtained by Easy FEM software to solve the solutions.

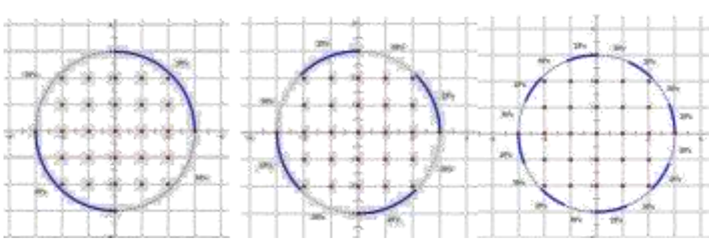


Fig. 4 Grid points for finite difference method

V. RESULT

Solve the linear systems by using Mathematica software. The results of each pattern are shown as in the next page. The temperatures from left edge to center which received from finite difference method are presented in fig. 5

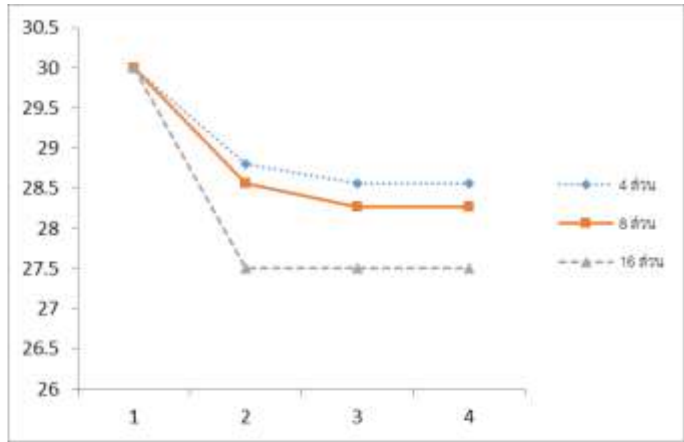


Fig. 5 Comparison of the temperatures from left edge to center

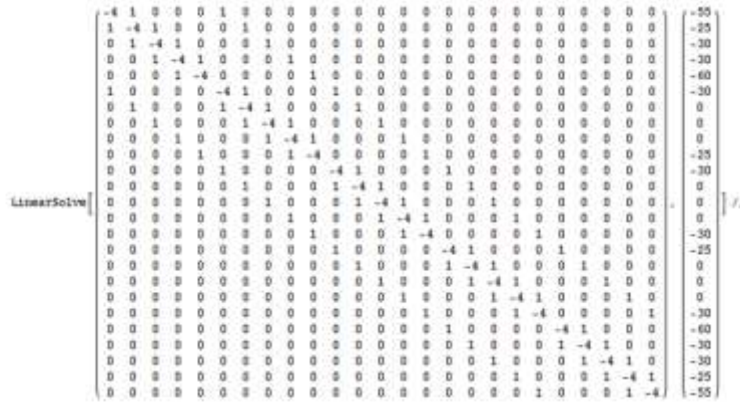
From fig. 5, we found that the temperature decreased steadily from the left of the cylindrical building to the center. Temperature average and temperature at center are shown in this following Table

TABLE I TEMPERATURE INSIDE EACH BUILDING PATTERN.

Patterns	Pattern1	Pattern2	Pattern3
Temperature Average	28.496156	28.115392	27.5
Temperature at center	28.5577	28.2692	27.5

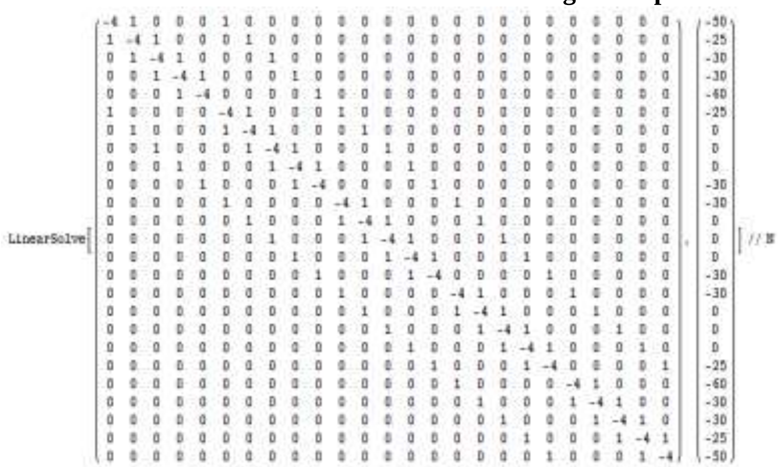
In the other hands, by using finite element method, the steady state temperature distributions within the three models of building with three different glass arrangement are illustrated in color contours in Fig. 6.

Pattern 1 Divide the building into 4 parts



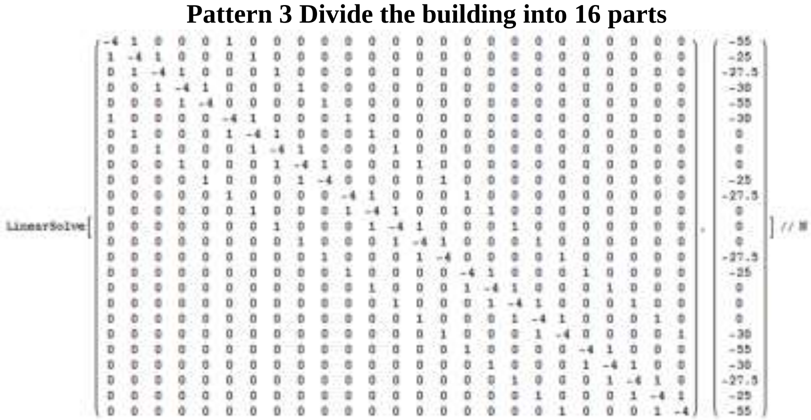
{{27.8045}, {27.484}, {28.7981}, {29.1506}, {29.2628}, {28.734}, {28.3333}, {28.5577}, {28.5417}, {27.9006}, {28.7981}, {28.5577},
{28.5577}, {28.5577}, {28.7981}, {27.9006}, {28.5417}, {28.5577}, {28.3333}, {28.734}, {29.2628}, {29.1506}, {28.7981}, {27.484}, {27.8045}}

Pattern 2 Divide the building into 8 parts



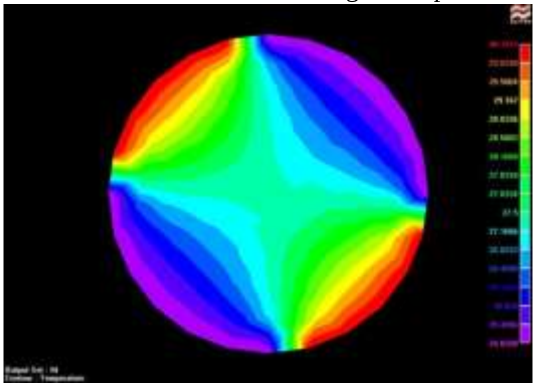
{{25.8654}, {26.7308}, {28.5577}, {29.2308}, {29.6154}, {26.7308}, {27.5}, {28.2692}, {28.75}, {29.2308}, {28.5577}, {28.2692},
{28.2692}, {28.2692}, {28.5577}, {29.2308}, {28.75}, {28.2692}, {27.5}, {26.7308}, {29.6154}, {29.2308}, {28.5577}, {26.7308}, {25.8654}}

Pattern 3 Divide the building into 16 parts

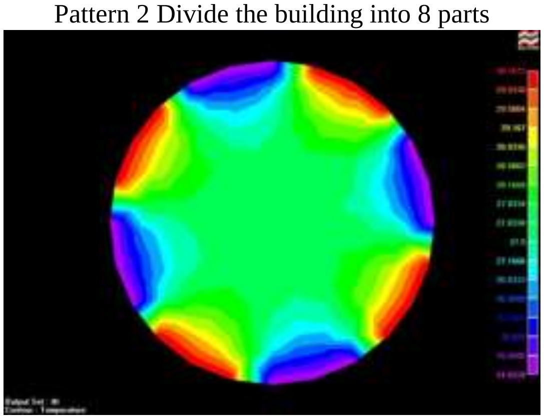


{{27.5}, {26.875}, {27.5}, {28.125}, {27.5}, {28.125}, {27.5}, {27.5}, {27.5}, {26.875}, {27.5},
{27.5}, {27.5}, {27.5}, {27.5}, {26.875}, {27.5}, {27.5}, {27.5}, {28.125}, {27.5}, {28.125}, {27.5}, {26.875}, {27.5}}

Pattern 1 Divide the building into 4 parts



Pattern 2 Divide the building into 8 parts



Pattern 3 Divide the building into 16 parts

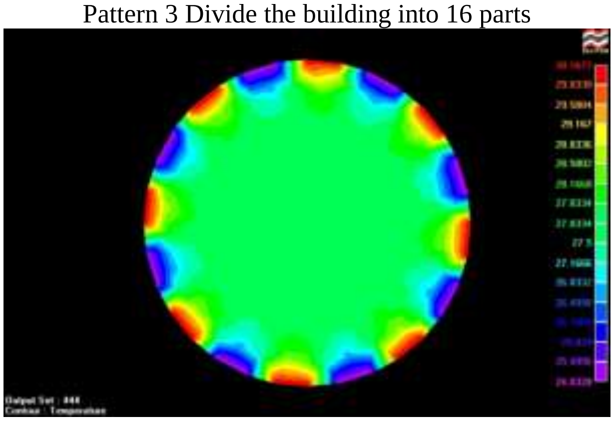


Fig. 6 Color contours of temperature distributions

The temperature (T) decreased steadily from the edge to the center. The heat transfer patterns of the three different glass arrangement followed the similar trend but were not identical. We found that heat was transferred more easily through the building that divided 4 parts than 8 parts and 16 parts, respectively.

A comparison between the temperatures from left edge to center which received from finite element method of each patterns is shown in Fig 7.

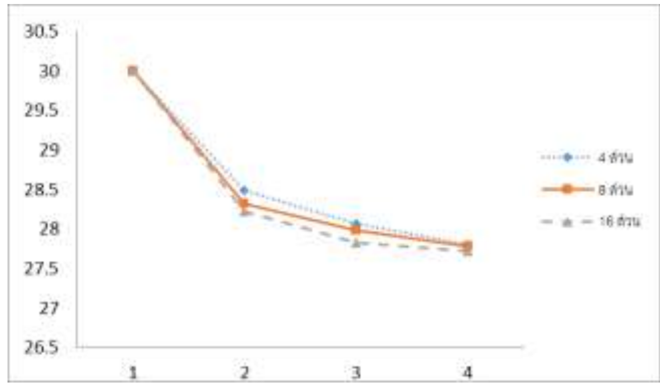


Fig.7 Temperature from left edge to center of each pattern by Finite Element Method

Both methods, the finite difference method and finite element method, provided solutions in the similar trend. Pattern that divide the building into more parts helps the heat to pass through slightly less. Finite difference method gives a slightly less realistic result due to the less curved domain and less internal resolution.

VI. CONCLUSION

The results from both Finite Difference Method and Finite Element Method shown that glass arrangement patterns effect to temperature distribution passed into the building. Heat was transferred more easily through the building that divided 4 parts than 8 parts and 16 parts, respectively. Glass has a higher temperature than concrete walls. If the area of the glass is equal. The more the glass divided into smaller pieces, the temperature inside the building reduce more. Hence, choosing the right glass arrangement can reduce the impact of heat entering into a building.

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