A Study of The Number of Chilling Pipes With Water And of Their Position In A Wall For Air-Conditioned Space, Part A

Abass K.I.[*1], Freegah B.[#2]

[*]Mechanical Engineering Department, Faculty of Engineering, Mustansiriyah Universit , Baghdad, Iraq

Abstract - *A new type of air-conditioned space using a radiant cooling/heating system with application in regions known for high differences in temperature throughout the day, has been studied. The effects of the number and position of the pipes within the walls have been analyzed using the finite element method (FEM). The results have shown that the number of the tubes has higher effect, approximately 30.5%. Furthermore, the location of the pipes in the inner surface of the wall has the effect of about 14.3%. In addition, the equation to predict the working fluid temperature within the pipes has been developed with about 89% accuracy.*

Keywords - *Air condition, cooling/heating system, finite element method FEM.*

I. INTRODUCTION

The radiant cooling/heating systems have been widely used in many areas with high temperature differences between night and day. These systems have many advantages, as compared to the traditional air-conditioning, such as saving energy, more comfort and health [1-5]. The traditional air-conditioning system has some disadvantages, such as high humidity, noise, etc. and to avoid these drawbacks, many researchers have tried to develop new methods for air-conditioning systems installation. However, most of those researchers, have studied widely the effect of the cooling/heating system on space of air-conditioning for both the flooring and the ceilings. An experimental study on the ONDOL performance of the system's floor heating, using ten types of covering materials, was conducted by Song [6]. The results showed that the contact lower coefficient of covering material is more stable to temperature fluctuations at the surface of the floor as compared with other covering materials. Xing Jin et al. [7] conducted a numerical study to investigate the velocity of water and the effect of the pipe resistance on the thermal performance of the floor cooling system. The results indicated that the velocity of working fluid has negligibly small effect, whereas the material of the pipe has significant effects on the performance of the floor cooling system. A numerical study by finite element method to illustrate the effect of design parameters on the thermal performance of a radiant floor heating system has been conducted by Sattari and Farhanieh [8]. The results showed that the cover material, the floor thickness, and the type of the floor were significant important parameters on the radiant heating system design.

However, in the literature, many researchers have extensively studied the ceilling and floor cooling/heating systems. The number of research regarding the walls cooling/heating system is significantly lower. The effect of the number and position of the pipes within the wall on the performance of the cooling/heating system using the finite element method has been conducted. The effect of the parameters considered in this study has not yet been clearly analyzed in the design process of the wall cooling/heating system. Hence, this research is important for the methodology design of the wall cooling/heating systems.

II. STANDARD CONDITIONS OF THE AIR-CONDITIONING

There are several parameters that have effects on the air-conditioned space and hence on human comfort. These parameters include:

- The rate of airspeed in the room at a value associated with the dry bulb temperature, and the process of heating or cooling.
- The relative humidity should be within the limits of 40% and 60%, while preserving the value of 50% of the design, and the relative humidity should not exceed 70% in summer and should not be less than 20% in winter [9 and 10].
- The average temperature of radiation in winter is higher than in summer.

III. NUMERICAL MODELING

In order to create a code for a solution for such a problem, some steps have been followed, as shown in figure 1. The steps that have been created are the simulation model, the meshing, the boundary condition, etc.

Geometry: a section of two-dimensional computational geometry of the wall has been created for the numerical simulation models, in Ansys [11], as shown in figure 2. The geometry consists of the wall (0.3 m), where 0.27 m is the thickness of the structure (hole wall) and 0.03 m is thickness of the outer layer of the wall. The model has a length of 1.54 m. The pipes were placed inside the wall, at the middle of the thickness of the wall (0.135 m), measured from the limit of the inner wall and at a third of the thickness of the wall measured from the internal surface of the wall. Table 1 represents the specifications of the wall components used for this simulation. To analyze the impact of the number of pipes on temperature distribution around the pipes within the wall and on the extension of the inner side wall, and hence on the thermal performance, three, five and ten pipes have been used. In addition, three positions of pipes (1/3, 1/2 and 2/3) distance from the internal wall surface of the room have been considered to study the effect of the position of the pipes. The paint was taken according to the specifications of the required material and was placed as a direct contact with the wall and along its surface.

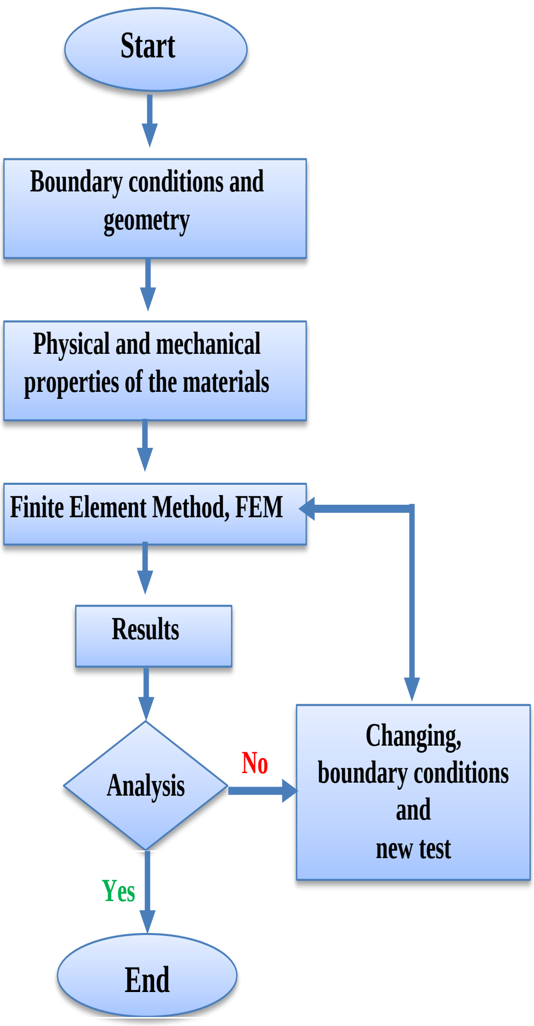

Fig. 1. The basic steps of the simulation model

Table 1. Specification of wall materials [12 and 13]

Item	Outer layer	Wall opening	Inner layer
Type of structure	Coating	Block	Whiteness
Type of material	White Cement + Sand	Brick or Cement Block	Gypsum + matt lime
Thickness, t, mm	15	270	15
Density, ρ, kg/m^3	1100	1400	1441
Thermal conductivity, k, W/m^2.k	0.81	0.72	0.721

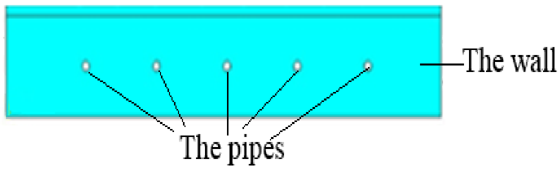

Fig. 2. A section, 2D-Geometry of the wall

Governing equations: the energy equation for the conduction, which occurs through the different materials:

$$K_m\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)=0$$
(1)

where K_m is the thermal conductivity of the material.

Meshing: hybrid meshing has been employed in the present study, using both hexagonal and tetrahedral elements, as shown in figure 3. Plane-77 has been selected to represent all structures of the wall. The elements were distributed along the length and width of the wall (10 elements in width, 60 in length), while around the pipes, a large number of small elements has been selected.

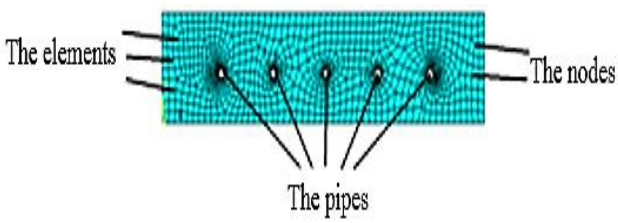

Fig. 3. Meshing of the wall

Boundary conditions: The performance of the wall heating/cooling system has been studied under three positions of pipes (1/3, 1/2 and 2/3) distance from the internal wall surface of the room, and for three different pipes number (three, five and ten). The external surface is affected by ambient temperature during the day, by the natural thermal source as shown in figure 4. The inner surface of the wall is considered to be a surface affected by temperature changes in the air-conditioned space, as shown in figure 5.

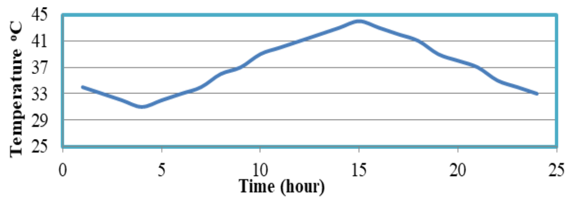

Fig. 4. Outside wall temperature variation during the whole day

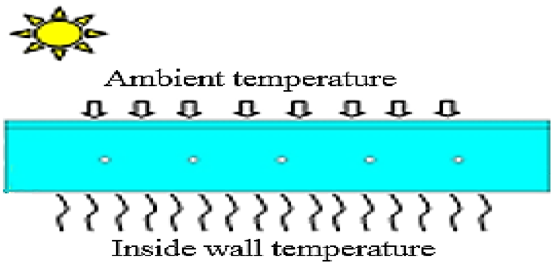

Fig. 5. Boundary conditions

IV. RESULTS AND ANALYSIS

There are several parameters that have effects on the air-conditioning of a space. One of the most important of these parameters is the heat transfer through the wall and ceiling. The amount of this heat reached approximately 70% of the total heat that should remove by the air-conditioning system. According to this fact, the wall heating/cooling system has been used for air-conditioning of the building. The wall heating/cooling system considered two aspects, the number of the pipes used, and location of the pipes within the wall. Using the pipes for changing the space temperature inside the room is presenting loading conditions correspond to both steady and transient loadings.

Wall Temperature Analysis

The temperature distribution within the wall heating/cooling system is depicted in figure 6. In order to illustrate the behavior of the temperature at any point within the wall, temperature distributions from three sides for the wall have been shown. It can be seen clearly that the temperature between the pipes and around them are lower than in other regions of the wall. The reasons behind is the cool water, which flows through the pipes. Furthermore, the temperature of the outer surface of the wall at the near region is higher than the inner surface of the wall and the region close to it because the surrounding air temperature outside is higher and directly affected by the sunrays. The inner surface and the region beside it is have lower temperatures, because they are affected by the cold water, which flows within the pipes.

Figure 7 shows the temperature variation within the wall for a 24-hour duration for the case of five pipes at the center of the wall. It can be seen that the temperature of the wall increases, then decreases according to the ambient temperature, which depends on the time of day. Furthermore, along the width of the wall, the temperature fluctuates because of the pipes within the wall.

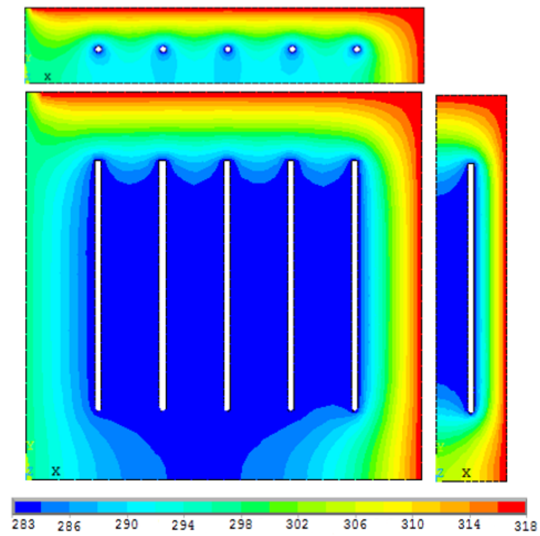

Fig. 6. Temperature distributions within the wall for five pipes at the wall center

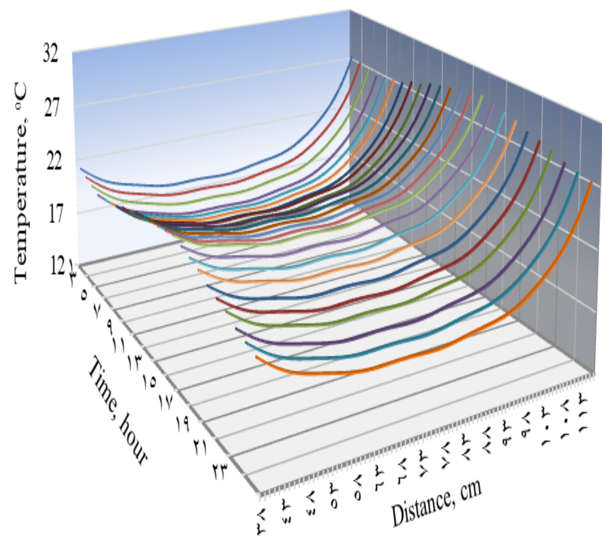

Fig. 7. Variations in temperature within the wall for five pipes at center of the wall during a day

Effect of the number of pipes

The effect of temperature in the traditional model (without pipes) starts from the outside of building due to the sun effect, and that effect continues until the influence of the shadow region is started, as shown in figure 8(a). Using 3, 5, and 10 pipe in the middle of the wall helps decreasing the temperature distributions along the inner side of the wall by preventing the heating load or moving the heat translation through the wall section, as are presented in the figure 8 (b, c and d). Any increase in the number of pipes means increasing the amount of working fluid, which is considered as resistant to the heat load that comes from outside through the wall into the inner space. In addition, the heat loads that cross between the pipes is lower for the case with ten pipes as compared to the other cases, c and d.

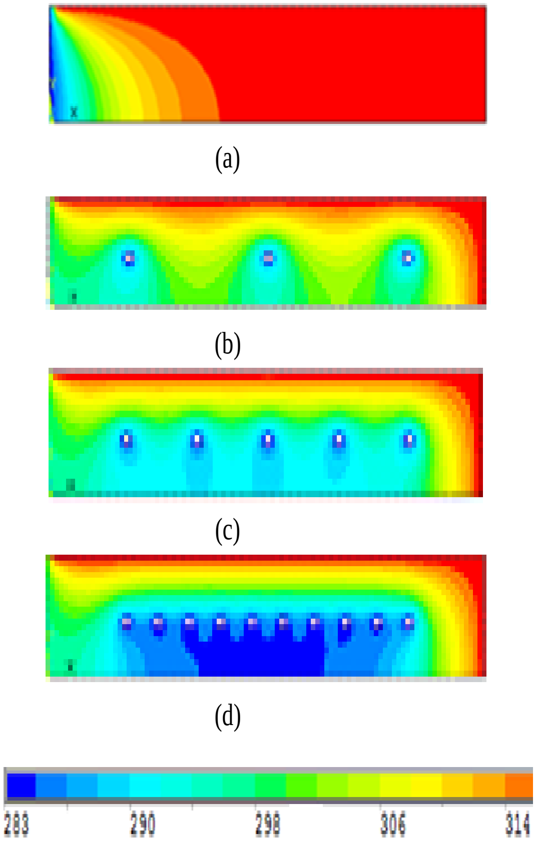

Fig. 8. Temp. distributions inside the wall a) without pipes b) 3 pipes c) 5 pipes and d) 10 pipes

The temperature distribution within the walls and around the pipes of the four cases a, b, c, and c are presented in figure 9. It can be clearly seen that the temperature within the wall is the highest for the traditional case, compared to other cases. Moreover, the average temperature of the wall for the traditional model, three pipes, five pipes, and ten pipes is 49.34 °C, 25.72 °C, 17.22 °C and 13.48 °C, respectively. Furthermore, it can be seen that the temperature of the wall is decreased with an increased number of pipes within the wall.

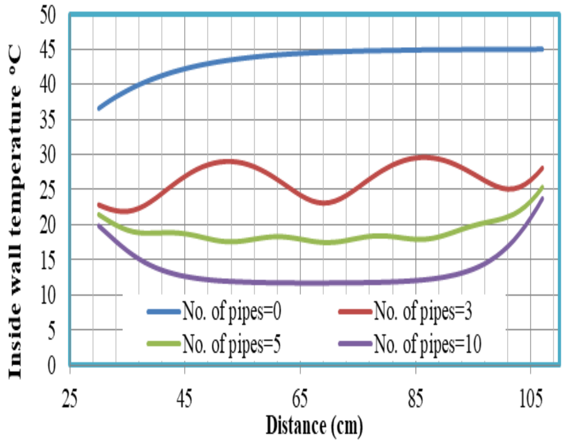

Fig. 9. Variations in temperature inside the wall for all cases regarding the number of pipes

Effect of position of the pipes

The temperature distribution within the wall consisting of three sections, as mentioned in table 1, for all cases considered in the current study, is depicted in figure 10. It can be clearly seen that the hot section occupies the outer side of the wall, while the cold section settles on the inner side of the wall for all cases. This happens because of the flow of cold water through the pipes installed within the wall. Furthermore, it can be seen that the case with pipes near to the inner side of the wall has more positive effects on the air-conditioned space as compared with the other cases.

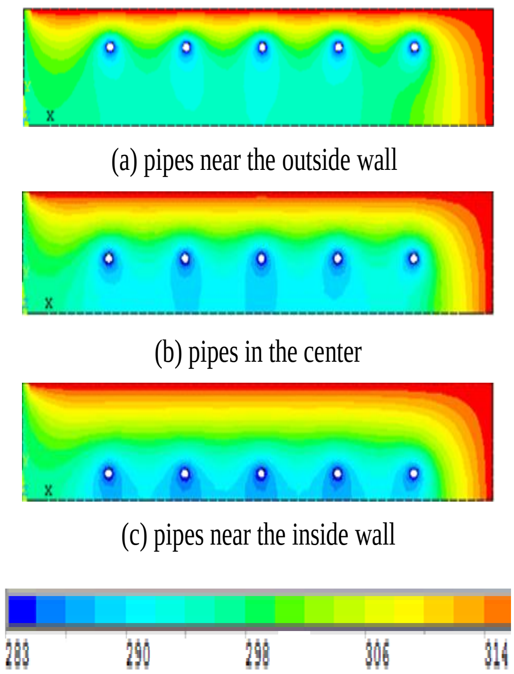

Fig. 10. Temperature distributions within the wall for various pipes locations

The variations in wall temperature for different positions of the pipes for the case of five pipes are presented in figure 11. It can be seen that the temperature within the wall is lower for the pipes near the inner wall, as opposed to the other cases. Furthermore, the temperature distribution for the case with the pipes near the outside wall has a wavy shape, while the medial pipes case. The installation with pipes near the inner wall indicates a smooth curve.

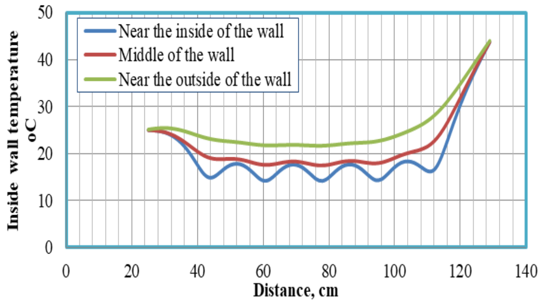

Fig. 11. Variations in temperature of the inside wall for various positions of pipes within the wall

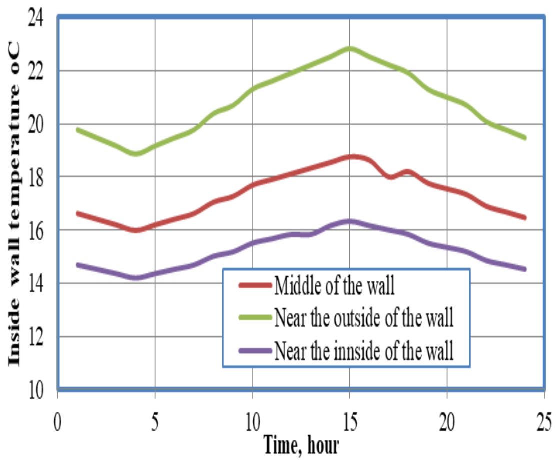

Fig. 12. Variations in the temperature of the wall for various positions of pipes within the wall

The variations in temperature within the wall for all cases of pipes positions, considered in the current study are depicted in figure 12. It can be clearly seen that the temperature within the air-conditioned space is higher for outside of the wall as compared to other cases. Furthermore, it can be seen that the temperature of the air-conditioned space with the case of pipes near the inner side of the wall is lower as compared to the other cases (medial and near outside of the wall).

Working fluid temperature Prediction

From the numerical results, using multiple regression analysis, equation 2 has been used in order to calculate the temperature supply of the working fluid for various numbers of pipes and different positions of the pipes. The following steps have been taken.

1. After conducting the parameters effect investigation using the proposed FEM model, the acquired results have been classified according to the level of their effectiveness (all parameters that have an effect on temperature supply are considered as variables and arranged in the equation for temperature supply according to these variables).
2. The above classification has been employed to obtain dimensionless equation using several forms (both sides of the equation are equilibrium regarding units) for the depended and independent variables, which are the number of pipes, the position of these pipes and temperature of the space.
3. To calculate the indices and factors for each term in the equation, different mathematical approaches adopted in the regression have been used, such as $\log_{10}$, power, line, etc. However, it was found that $\log_{10}$ is the most accurate way, as R^2 scored the highest value in this case among the others.
4. Microsoft Excel was used as a tool to conduct the regression.

To categorize the accuracy level of equation 2, the determined data from the equation has been plotted against the numerical data from FEM.

$$T_{s.w.f} = 0.411\, T_{sp}\left(np_{pipes}\right)^{0.539}\left(\frac{Po_{pipe}}{Th_{wall}}\right)^{0.372}$$

(2)

where, $T_{s.w.f}$ and T_{sp} represent the temperature supply of the working fluid and space temperature of air-conditioning, respectively, while np_{pipes}, Po_{pipe} and Th_{wall} represent the number of pipes, pipes positions, and wall thickness, respectively.

The variations in the temperature supply of the working fluid determined using the established equation and that have been obtained from the FEM model are represented in figure 13. It can be seen in this figure that the maximum difference between them is 11% and most of the points are well below that error margin. Therefore, according to this observation, the equation can be used to predict the temperature supply of the working fluid with 89% accuracy.

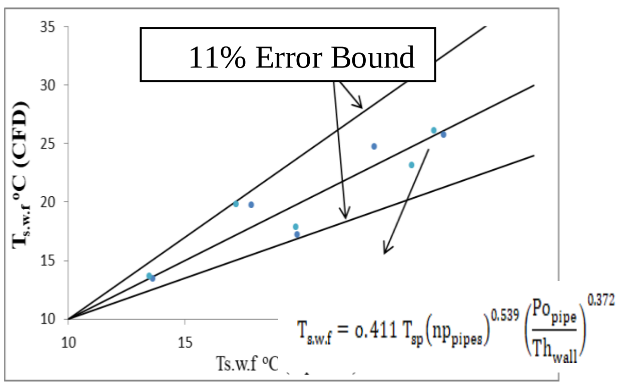

Fig. 13. temperature supplies of the working fluid variations

In order to validate the helpfulness of an equation established using multiple regressions analysis, numerous statistical tests have been carrying out. Table 2 illustrates that the derived equation for the temperature of the working fluid has achieved the satisfactory criteria for all the tests. The equation of the working fluid temperature can be used with confidence for further applications.

Table 2 Statistical tests and acceptance criteria for the working fluid temperature

Type of test	**Acceptance criteria**		**Eq. (1)**
F-value	If (F < F critical) is accepted [14]	F	1.416
		F cri.	2.978
Durbin-Watson statistic	Less than 2 is accepted [15]		1. 281
t-Test	Closed to zero [16]		0.00013
Lilliefors test	If 0= accepted If 1= rejected [17]		0
Chi-square	Less than 0.05 is accepted [18]		0.0241
P-value	More than Chi-square is accepted [18]		1

V. CONCLUSIONS

The effects of various parameters, such as the number of pipes and position of pipes have been numerically analyzed. It can be concluded that the effect of the number of pipes and their position influence the performance of the wall heating/cooling system and hence the air-conditioned space. The number of pipes has more effect on this system as compared with the position of the pipes. Furthermore, an equation to predict the temperature of the working fluid within the pipes, which comes from chiller, has been developed, validated with high accuracy tests that have been conducted. In addition, it can be concluded that the Finite Element Method, FEM can be used as an effective tool to analyze the performance of the wall heating/cooling system with reasonable accuracy.

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