NUMERICAL INVESTIGATION TO EVALUATE HEAT REDUCTION OF USING BURIED WATER PIPE INSIDE EXTERNAL WALL [+]

دراسة عددية لتقيم التخفيض في كمية الحرارة بأستخدام الأنابيب المائية المدفونة في الجدران الخارجية

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المستخلص:

أجري في هذا البحث دراسة عددية لمعرفة تأثير أنابيب الماء المدفونة في الجدران الخارجية على تقليل الكسب الحراري ومنع انتقال الحرارة الى داخل الفضاءات المكيفة. نتائج البحث أضهرت أن هنالك أمكانية لتقليل الكسب الحراري عند قيم محددة من العوامل المؤثرة مثل عدد الأنابيب للمتر الواحد من طول الجدار ونسبة قطر الأنبوب الى سمك الجدار و درجة حرارة الماء الداخل الى الأنبوب. بينت النتائج ان هنالك تخفيض بنسبة ٨٢ % مقارنة مع الجدار الخالي من الأنابيب عندما يكون عدد الأنابيب للمتر الواحد هو ٣ ونسبة قطر الأنبوب الى سمكه (D/W) بحدود ٠,٢ ودرجة حرارة الماء الداخل الى الأنبوب هي ٢٠ °C ، بينما بلغت أقل نسبة من التخفيض والبالغة ٢٤ % عند نفس عدد الأنابيب(٣) لكل متر من طول الجدار ونسبة قطر الأنبوب الى سمك الجدار هي ٠,٢ ايضاً ولكن درجة حرارة الماء الداخل الى الأنبيب هي ٢٥ °C. كما وقد أضهرت النتائج بأن هنالك تأثير بسيط جداًعلى كمية الحرارة المنتقلة خلال الجدار عند تغيير موقع الأنبوب داخل الجدار.

Abstract:

A numerical study has been done to evaluate the utilization of a water pipe buried inside an external wall to reduce the heat gain and prevent the transmission of heat energy inside the conditioning space in summer season.

The result of this paper shows that the reduction in heat gain could be occurred with specific values of parameters like a number of pipes per square meter, a ratio of pipe diameter to the wall thickness, and a pipe inlet water temperature.

Comparing with normal wall (without pipes), the result shows a significant reduction in heat gain which is about 82% when number of pipes per meter of wall length is 3.0 , the ratio of pipe diameter to the wall thickness (D/W) is 0.20, and the water inlet temperature is 25°C while the minimum ratio of reduction 24% is achieved when a number of pipes per meter , the ratio of pipe diameter to the wall thickness, and the water inlet temperature are 3.0, 0.2, 20°C respectively. The results also show that there is a very small effect of pipe center position inside the wall on the final heat transmission.

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Nomenclature

ρ : density	(kg/m^3)
X/W : pipe position to the wall width ratio	
X/W : pipe center position to the wall width ratio	
T_{pipe} : pipe surface temperature	(°C)
T_i^{P+1} : temperature on node i after a time increment $\Delta\tau$	(°C)
T_i^P : temperature on node i at particular time	(°C)
R_{ij} : thermal conduction or convection resistance	(m.°C/W)
Re : Reynolds number	
Q_k : heat gain by water in k- element	(W)
q_i : heat delivered to the node i by heat generation	(W)
Pr : Prandtel number	
Nu : Nusselt number	
k_f : fluid (water) thermal conductivity	(W/m.°C)
h_f : convection heat transfer coefficient	(W/m^2.°C)
h_f : convection heat transfer coefficient inside the pipe	(W/m^2.°C)
D/W : pipe diameter to the wall width ratio	
D : pipe diameter	(m)
c_p : specific heat	(J/kg.°C)
$\Delta\tau$: time increment	(s)
ΔV_i: volume of the element	(m$^{3)}$
$\dot{m}$: water mass flow rate	(kg/s)
$T_{f_{k+1}}$: water element outlet temperature from the node k	(°C)
T_{f_k} : water element inlet temperature in the node k	(°C)
$T_{f_{ave}}$: water element average temperature	(°C)
Two : outside wall temperature	(°C)
Twi : inside wall temperature	(°C)

Introduction:

Saving energy is one of the most important global challenges in our days. The facts that our resources are limited and that the use of energy contributes excessively to pollution and to the greenhouse effect are examples for the necessity to act in this field [1].

It is not strange to say that the power consumption in air-condition of a building especially in the hot area, forms an important figure of total power consuming a certain country. And, one of the important component of the air-conditioning thermal cooling load is the amount of heat transfer from the external wall to the internal condition space (by conduction) on the other side, sometimes the problem of uncomforted zones (unique temperature distribution inside the space) inside space could be appeared beside or near the external wall exposure to directly outdoor condition which required a special design to overcome this problem.

Tawee Vechaphitt [2] studied the effect of variation of shape and orientation of a building on the average heat gain, and analyzed the optimum shape of the building to minimize the average heat gain. In order to provide guidelines for reduction of that gain through the buildings and comparisons are made using four thermal insulating materials.

Joseph c lam and others [3] investigate the energy performance of the building envelopes in terms of the overall thermal transfer value (OTTV). To develop the appropriated parameters used in OTTV calculation, long-term measured weather data such as ambient temperature (1960–2001), horizontal) and global solar radiation on vertical surfaces (1996–2001) were examined. It was found that cooling loads and electricity use could be expressed in terms of a simple two-parameter linear regression equation involving OTTV.

R. saidur and others [4] Studied the overall thermal transfer value (OTTV) and the energy consumption of room air conditioning of the residential building (Malaysia). It is found that OTTV of the residential building varies from 35 to 65 W/m^2 with mean value of 41.7 W/m^2 . The sensitivities of several parameters such as window to wall ratio, shading coefficient (SC), U-value for wall and absorption (α) are provide the design optimum

T. Kiatsiriroal and M. Veekel [5] find that heat accumulated in the wall of an air-conditional building could be excreted by the circulation of water in a set of copper tube embedded at the outer wall surface. They found that the period of cooled wall operation, between 10 am. – 5 pm. , the cooling load could be 3.67 kWh/day compared with 4.56 kWh/day, for the normal wall.

From the previous notation and power saving wise, it's clear the important of particular treating with the external walls of circumference of building, and the attempt continues to prevent the transfer of heat before entering the building if it's possible.

The objects of the present work is to study the ability of utilization the buried pipes inside the external walls to reduce the heat gain and to study the effect of some important parameter like D/W, Water inlet temperature, pipe positions.

Theory and model:

In general, the thermal resistance-capacity formulation for the energy balance on a node using backward-difference, shown in figure (1), is [6]

$$q_i + \sum \frac{T_j^P - T_i^P}{R_{ij}} = C_i \frac{T_i^{P+1} - T_i^P}{\Delta\tau}$$

(1)

Thermal capacity C_i is defined as

$C_i = \rho\, c_p\, \Delta V_i$

The solution of equation (1) can be carried out by a number of methods. If the solution is to be performed with Gauss-seidel iteration technique, then equation (1) should be solved for T_i^{P+1} and expressed as

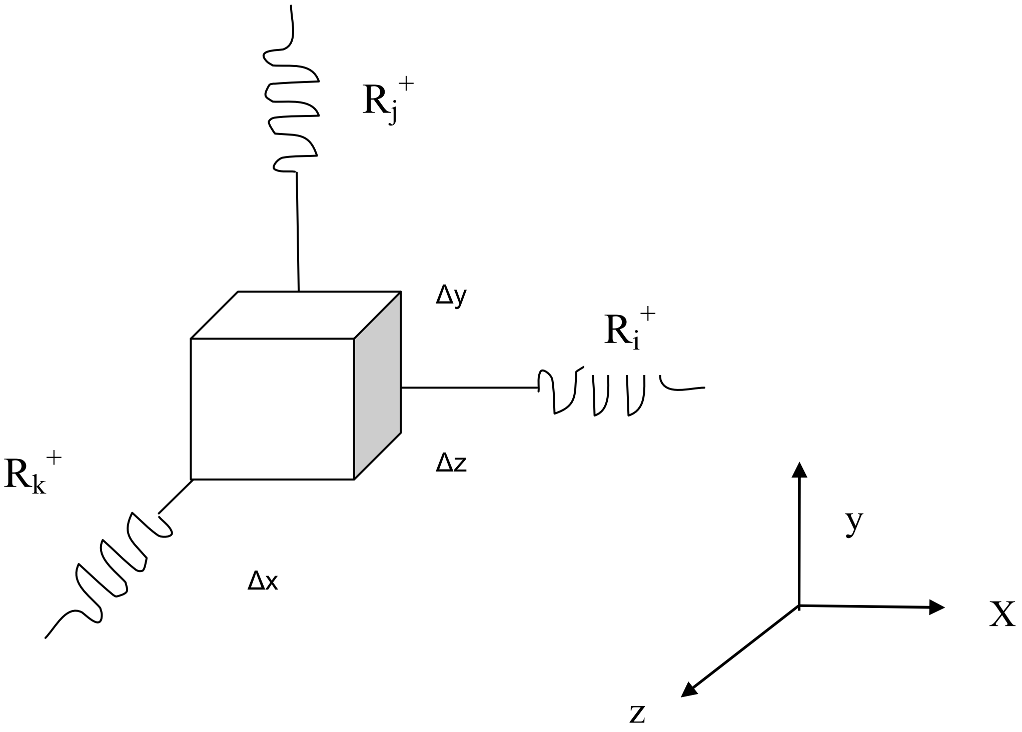

Figure (1) Element of model

$$T_i^{P+1} = \left(q_i + \sum_j \frac{T_j^P}{R_{ij}} \right) \frac{\Delta\tau}{C_i} + \left(1 - \frac{\Delta\tau}{C_i} \sum_j \frac{1}{R_{ij}} \right) T_i^P \tag{2}$$

To insure stability , one must keep Δτ equal to or less than the value obtained from the most restrictive nodal by solving for Δτ

$$\Delta\tau \leq \left(\frac{C_i}{\sum_j 1/R_{ij}} \right)_{\min} \tag{3}$$

The resistance element (R_{ij}) shown in Figure (1) for each node in the wall is given in Table (1)

Table (1) The resistance of nodes (R_{ij}) [7]

Node condition	R_i^+	R_i^-	R_j^+	R_j^-	R_k^+	R_k^-
Inside the wall	$\frac{KA_x}{\Delta x}$	$\frac{KA_x}{\Delta x}$	$\frac{KA_y}{\Delta y}$	$\frac{KA_y}{\Delta y}$	$\frac{KA_z}{\Delta z}$	$\frac{KA_z}{\Delta z}$
Convection on the left side (h_o)	$\frac{KA_x}{\Delta x}$	h_oA_x	$\frac{KA_y}{\square\Delta y}$	$\frac{KA_y}{\square\Delta y}$	$\frac{KA_z}{\square\Delta z}$	$\frac{KA_z}{\square\Delta z}$
Convection on the right side (h_i)	h_iA_x	$\frac{KA_x}{\Delta x}$	$\frac{KA_y}{\square\Delta y}$	$\frac{KA_y}{\square\Delta y}$	$\frac{KA_z}{\square\Delta z}$	$\frac{KA_z}{\square\Delta z}$

Heat gain within the water pipe:

Heat gain from the pipe imbedded inside the wall, shown in Figure (2), can be estimated by using the energy balance between the nodes,

$$\sum Q_k = \dot{m} c_p \Delta T \tag{4}$$

$$\sum [Q_k = \dot{m}_f c_p \left(T_{f_{k+1}}] - T_{f_k}\right) \tag{5}$$

Solve for $T_{f_{k+1}}$

$$T_{f_{k+1}} = \frac{\Sigma Q_k}{\dot{m} c_p} + T_{f_k}$$

$Q_k = h_f A_x \Delta T$

$$Q_k = h_f A_x \left(T_{pipe} - T_{f_{ave.}}\right) \tag{6}$$

To find the inside pipe heat transfer coefficient (h_f) using Dittus-Boelter equation for turbulent flow [6],

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \tag{7}$$

$$Nu = \frac{hD}{k}$$

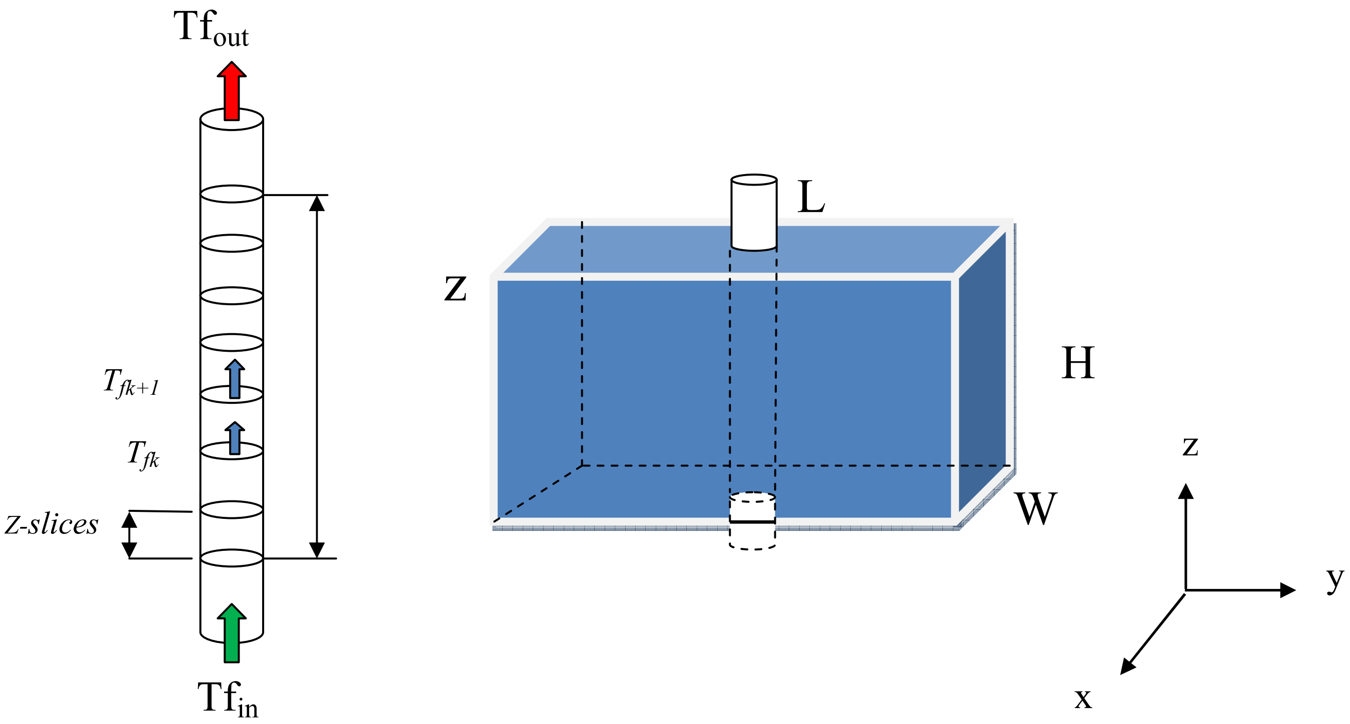

Figure (2) Water pipe embedded inside the wall

Initial and Boundary condition:

The initial condition of all nodes in the solution domain is assumed to be the average temperature between the outside and the inside temperature although the value of initial condition is not affecting significantly on the final results. And the boundary conditions which are employed in the present case study are listed in Table (2).

Table (2) Boundary conditions

Value of x, y, and z	Condition	Temperature	Remark
x=0	Outside surface	Two	
x=L	Inside surface	Twi	
y=0	Starting of simulation in y-direction	$\frac{\partial T_y}{\partial z}=0$	Similarity
y=W	End length of simulation in y-direction	$\frac{\partial T_y}{\partial z}=0$	Similarity
z=0	Starting of simulation in z-direction	$\frac{\partial T_z}{\partial y}=0$	Similarity
z=H	End length of simulation in z-direction	$\frac{\partial T_z}{\partial y}=0$	Similarity

Program and solution code:

FORTRAN code was designed to accomplish the numerical solution of the final set of liner equations by guiss-sedil iterative method (simple and well known) with suitable value of over relaxation factor and a relative error of 1.0×10^{-3}. Figure (3) illustrates the flow chart of the solution scheme.

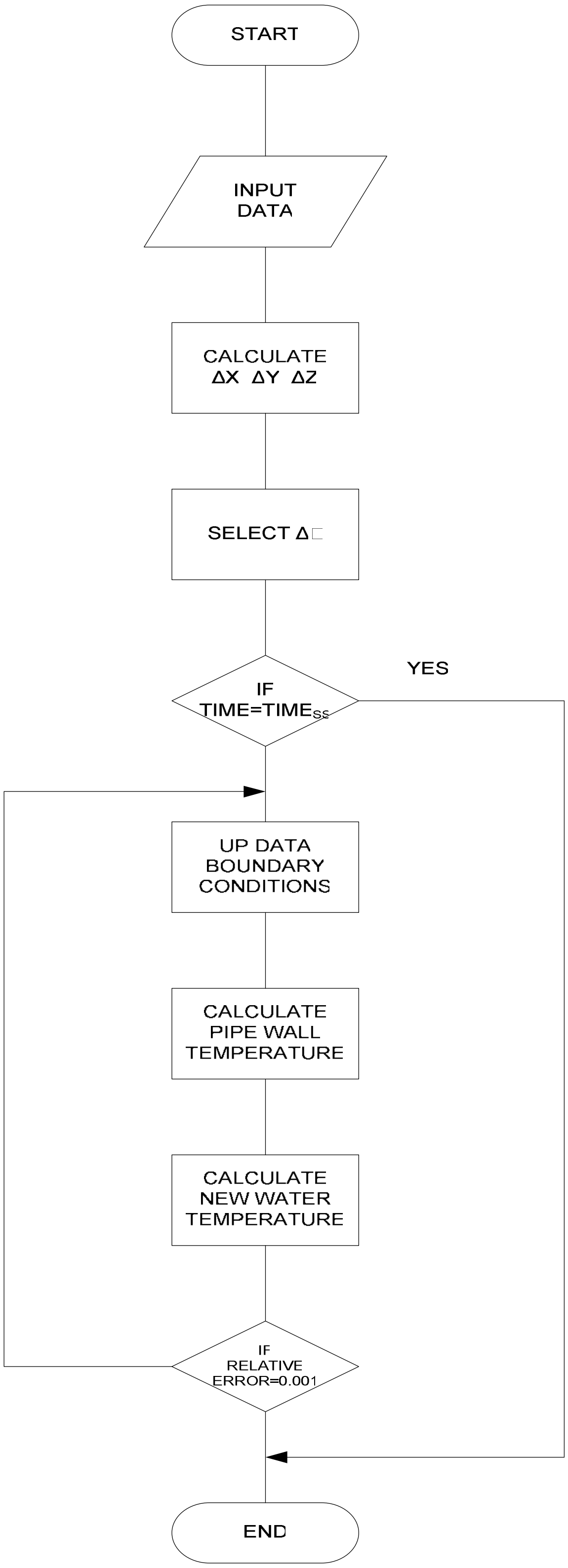

Figure (3) Program flow chart

Result and discussion:

The descritization of a 3-D model within 70×70×20 grid mesh is shown in Figure (4). Figure (5) shows the temperature distribution contour lines inside the normal wall (without pipe) to be compared with other cases, and Figure (6) to Figure (9) depict the effect of the pipe embedded inside the wall on the temperature contour lines. It's clear that the pipe works like a moderator or a heat sink to delay the high temperature contour lines to reach the inside wall, so it makes the average temperature of inside wall less than that without water pipe. Figure (10) shows the same effect of pipe on the contour lines but with different size of pipe per width of wall (D/W=0.3).

Figure (11) and Figure (12) explore the low significant effect of the position of the pipe center inside the wall on the heat transmitted to the space because at the steady state condition, the heat sink (water inside the pipe) position has no effect on the total heat transmitted.

Figure (13) and figure (14) summarize the effect of all parameters on the heat transmit inside the space with different number of pipes per meter of wall, water inlet temperature, and the ratio of pipe diameter to the wall width. The most important results obtained from these figures are the limitation of the number of pipes per square meter of wall with particular value of D/W which are making the heat transmitted to the space equal or less than the heat transmit without pipe and is leading the water pipe inside the wall to be not useful. Table (3) briefs the final results of these limits.

Table (3)Minimum number of pipes per square meter of wall to make the heat Transmutation is benefit

Water inlet temperature (°C)	D/W		
	0.2	0.4	0.55
20	3.0	2.0	1.0
25	No benefit	3.0	2.0
30	No benefit	No benefit	No benefit

Another point can be recorded on the same figure that there is no significant benefit (no heat gain reductions) to use the water pipe inside the wall when the temperature of water available in the air-condition plant is more than 30°C within any number of pipes per wall length and D/W, because at that condition, the water inside the pipe becomes a heat source instead of heat sink.

Table (1) gives us a good idea to predict or starting design of this type of system to selecting number of pipes per meter length and diameter.

Conclusion:

It can be conclude the following

1- Using buried pipes inside the external wall could be reduced the heat gain through the wall and then reduced the cooling load of buildings

2- Number of pipes per length of wall is the most important factor affect on the total heat reduction

3- Sometimes the pipe buried in the wall worked in the reverse action (increase the heat gain) if the water inlet temperature is too high regardless the number of pipes per length or pipe.

4- For the reason on civil structural considerations , it is not recommended to increase D/W

Recommendation:

It’s recommended to implement this study on the roof and other types of construction wall to know the effect of thermal storage in the wall and the effect of different type of fluid flowing inside the pipes.

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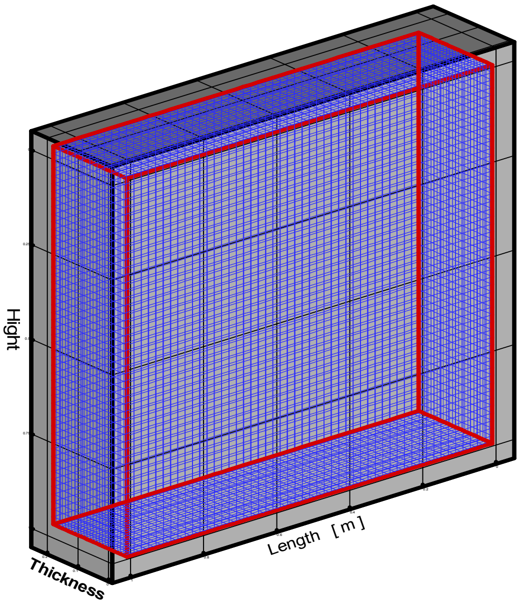


Figure (4) Discrtization of the model

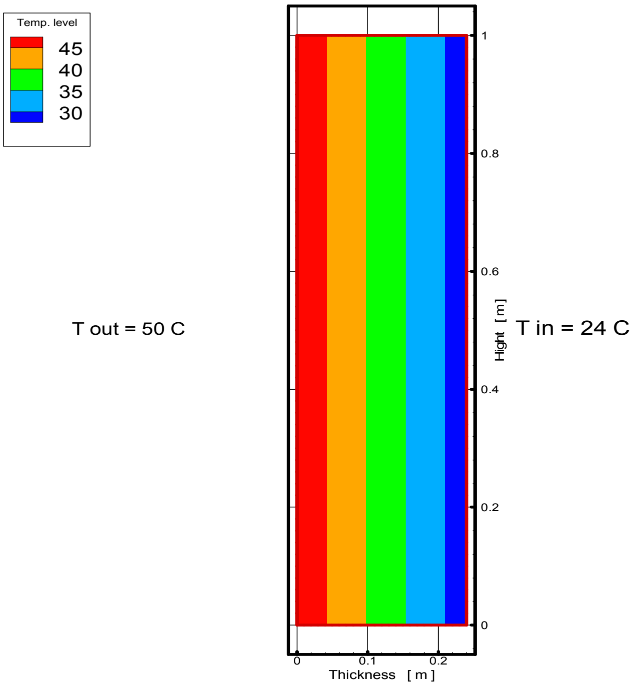
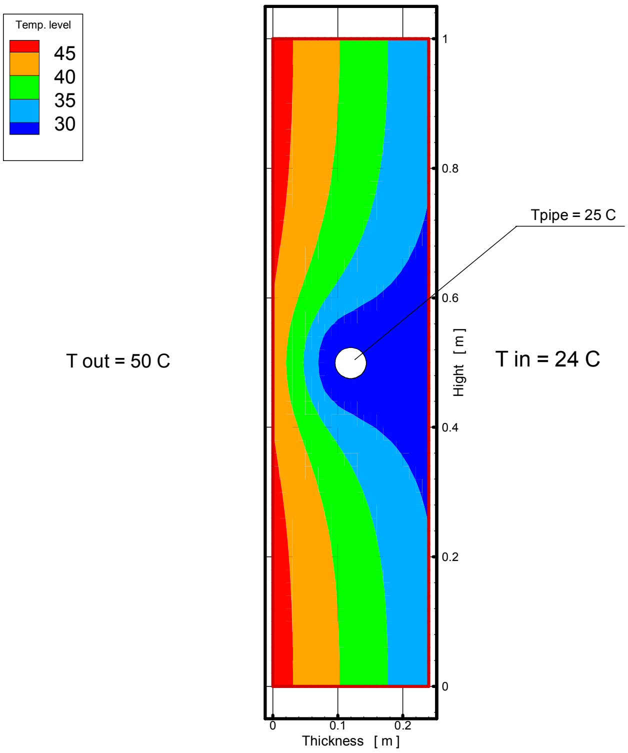


Figure (5) Temperature distribution in the normal wall (without pipe)



Figure(6) Temperature distribution of wall with D/W=0.2, Number of pipe per meter =1.0, and Tw_{in}=25 °C

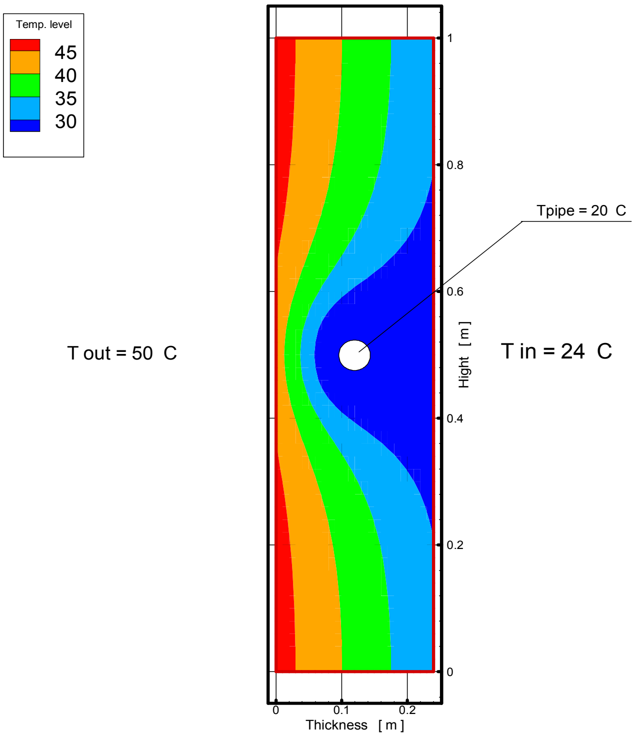


Figure (7) Temperature distribution of wall with D/W=0.2, Number of pipe per meter =1.0, and Tw_{in}=20°C

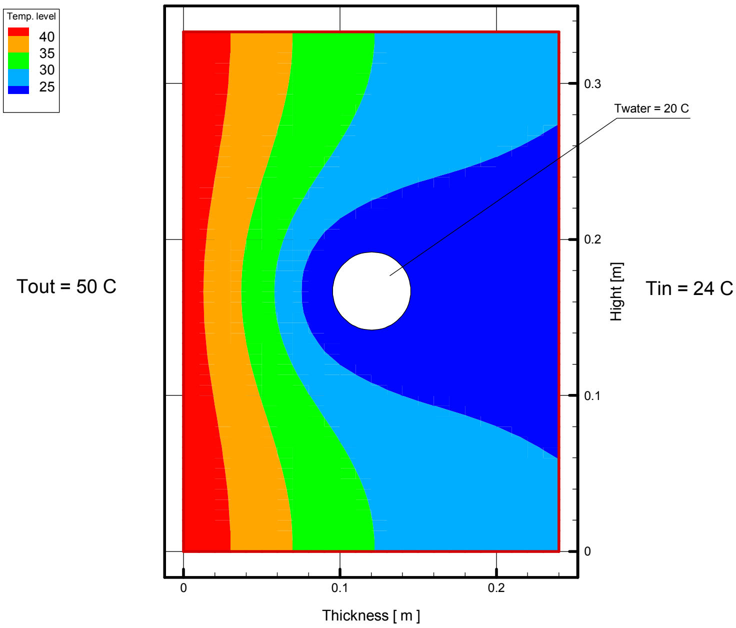


Figure (8) Temperature distribution of wall with D/W=0.2, Number of pipe per meter =1.0, and Tw_{in}=30 °C

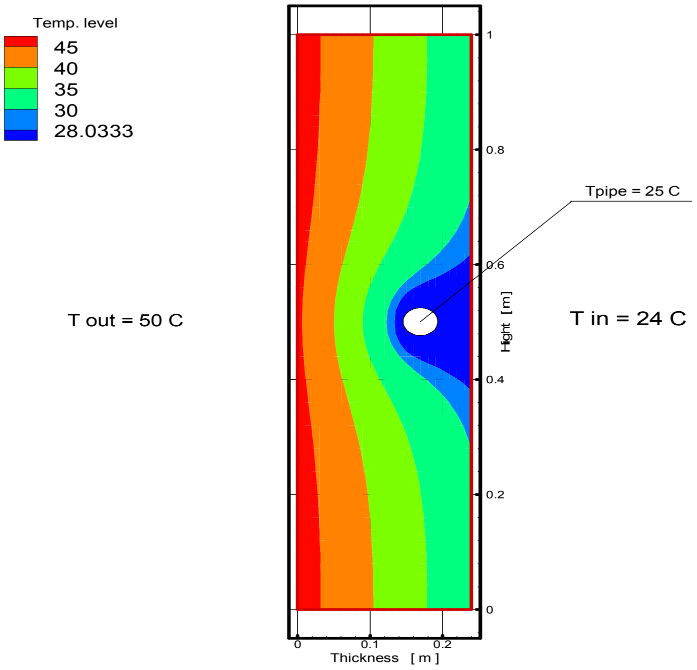


Figure (9) Temperature distribution of wall with D/W=0.4, Number of pipe per meter =1.0, and Tw_{in}=25 °C

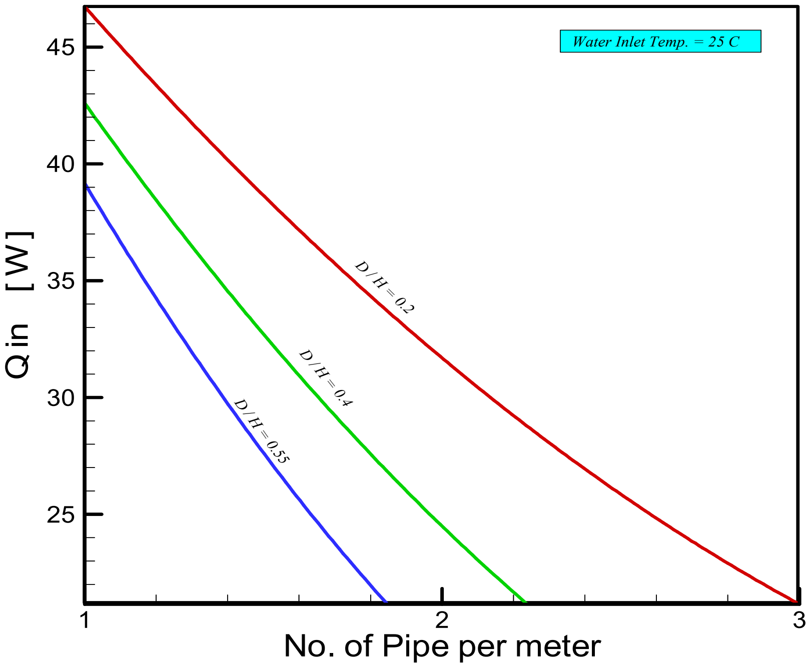


Figure (10) heat gain through the wall with different D/W and Number of pipe Per meter at water inlet temperature =25 °C

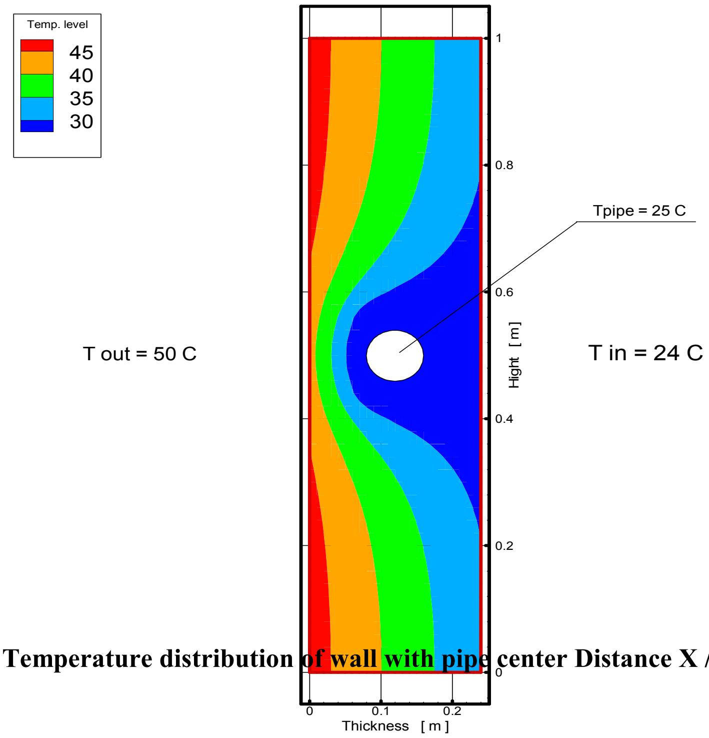


Figure (11) Temperature distribution of wall with pipe center Distance X /W=0.75

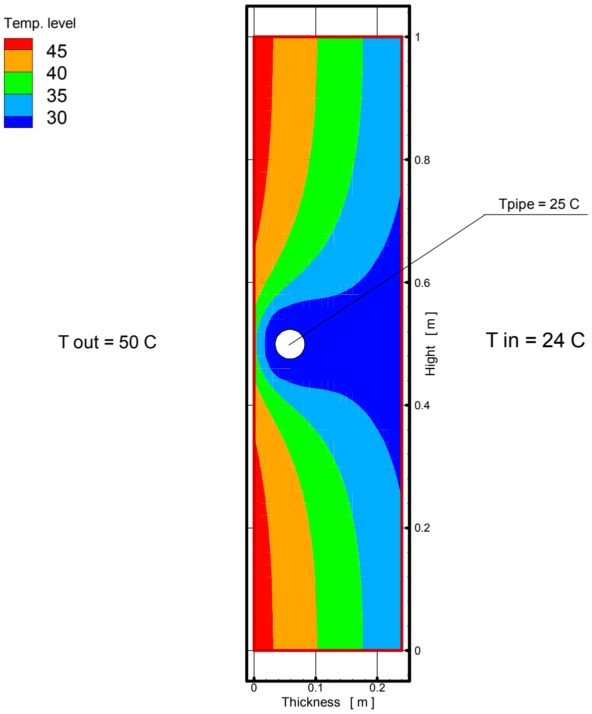


Figure (12) Temperature distribution of wall with pipe center Distance X /W=0.25

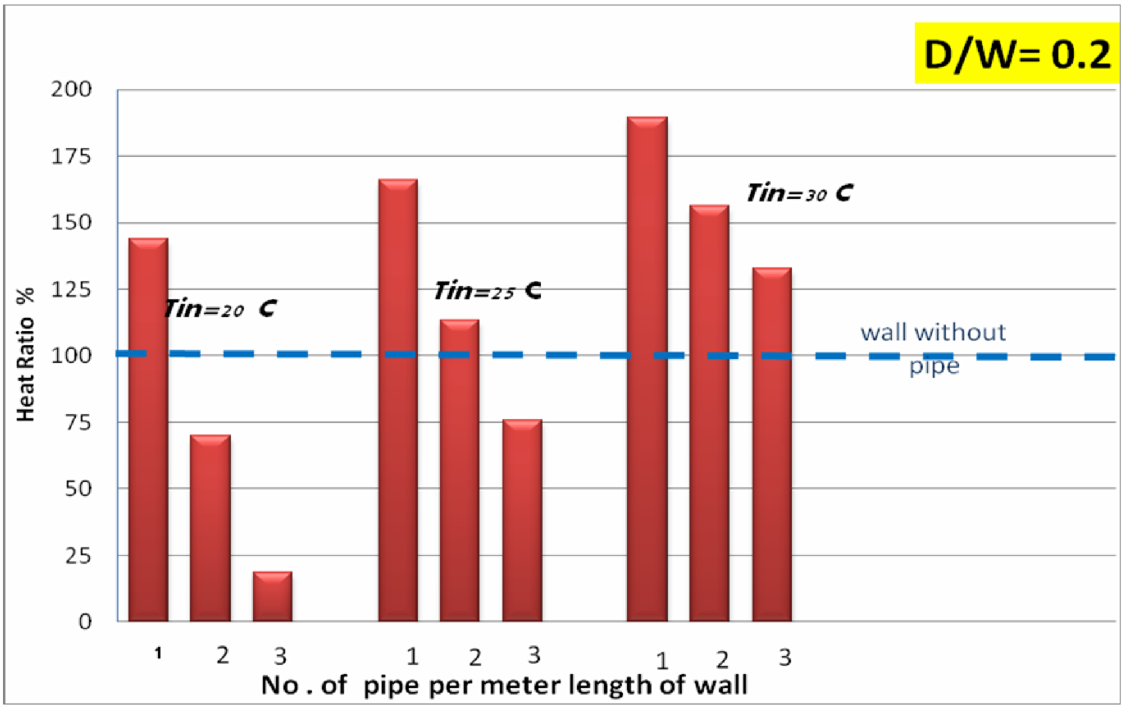


Figure (13) Ratio of heat entrance to the normal heat enter D/W=0.2

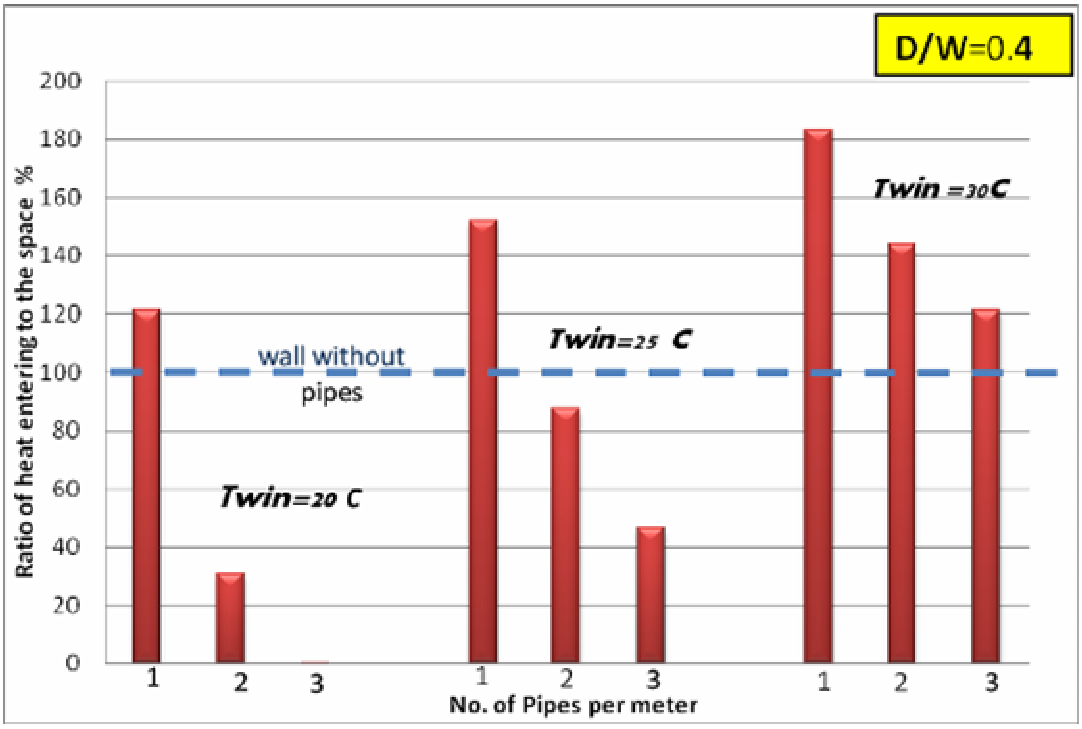


Figure (14) Ratio of heat entrance to the normal heat enter D/W=0.4