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Effect of water table depth on heat transfer through a slab-on-ground floor

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ABSTRACT
Heat loss or gain from buildings through contact with the ground is an important factor of efficient building design process. This factor has a strong impact on the energy demand especially of large residential or commercial buildings because they heavily depend on mechanical cooling or heating. The effect of water table depth on the total heat flux through a slab-on-ground floor has been previously analyzed explicitly, in this study the two-dimensional problem is solved using a fluent and Gambit software. Where was calculated the total heat flow from the floor of the building and the results were displayed graphically to the effect of water level depth when changing operational parameters and which are the temperature and convective heat transfer coefficients inside and outside the house. This study showed that the total heat loss from buildings occur primarily near the edge of the building as the results showed a significant effect of the water table depth on the heat flow through building floor at a depth less than 30 meters with the change of operational standards.

Keywords: *Heat flow; Building floor; temperature distribution; water table*

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I. INTRODUCTION

The energy conscious design and energy conservation has been the subject of international concern for many years. The construction and operation of buildings consume a large part of the world's natural resources and energy. In Western Europe it is estimated that more than half the energy consumed is used for heating and cooling purposes in buildings [1]. World energy use has almost trebled in the (30) years from 1960 to 1990. At the beginning of this current decade the electricity production in the European Community was The energy conscious design and energy conservation has been the subject of international around 1700 billion kWh and it is expected to increase by 20 - 40% by the beginning of the new millennium [1], It is acknowledged that this increasing energy demand has disastrous consequences for the environment (global temperature increase and damage to the ozone layer due to high levels of carbon dioxide and release of refrigerant fluids in the atmosphere)[2]. The energy conscious design and energy conservation has been the subject of international concern for many years.

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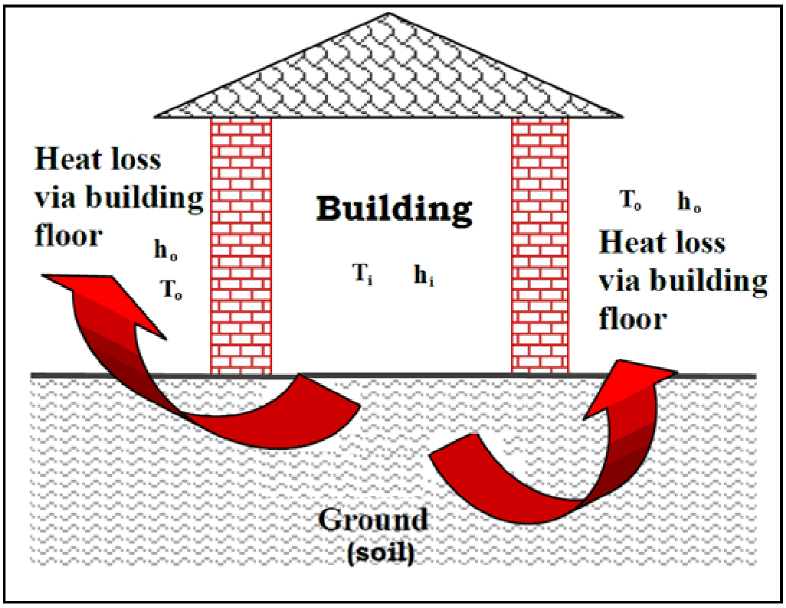

Fig.1 Heat loss from building to outside

Weitzmann et al. [12] states that a two-dimensional simulation model of the heat losses and temperatures in a slab on grade floor with floor heating which is able to dynamically model the floor heating system. The simulation model is coupled to a whole-building energy simulation model with inclusion of heat losses and heat supply to the room above the floor. This model can be used to design energy efficient houses with floor heating focusing on the heat loss through the floor construction and foundation. It is found that it is important to model the dynamics of the floor heating system to find the correct heat loss to the ground, and further, that the foundation has a large impact on the energy consumption of buildings heated by floor heating. S.W. Rees, Z. Zhou, H.R. Thomas [13] represent a numerical simulation of ground-heat transfer adjacent to an experimental earth–contact structure is presented, thermal conductivity and volumetric heat capacity have been described and employed. The results show good correlation between the simulated and measured thermal response. Hagentoft [14] presented general formulae, by which the heat loss and the temperature in the ground can be determined for the case of infinite ground water flow rate. Explicit analytical formulae for the temperature and the heat loss were given for several cases. He concluded that the relative increase due to ground water flow is smaller for insulated slabs than for un-insulated slabs. Chuangchid and Krarti [15] developed steady-state and steady-periodic semi-analytical solutions to determine the temperature field within the ground medium and within the concrete slab-on-grade floor where hot or chilled water pipes are embedded. They used this method to determine the ground heat loss/gain for a heated or cooled floor under various design conditions including the level of floor insulation. They presented detailed analysis to determine the effect of the soil and slab temperature field and on the monthly variation of the total slab heat loss. A general steady-periodic solution for foundation heat loss from heated concrete slab floors was developed using the ITPE technique. The developed solution accounts for the effects of floor covering and of water table below the foundation.

A finite element analysis was undertaken by Perry EH [10] to determine the effect of the following factors on the heat losses through residential floor slabs: Outdoor air temperature, deep soil temperature, thermal conductivity of the underlying soil, and configuration of any thermal insulation used. The study confirmed that the losses occur primarily near the edge of the slab and are proportional to the product of slab perimeter and the indoor/outdoor temperature difference, a relationship familiar to the HVAC community. M.H. Adjalia [16] State three case studies analyses using simple design calculations (those readily available to designers). It was found that the simplified calculation procedures may significantly over or under-estimate the actual value of heat loss (by up to 31% in the studied examples). This is perhaps understandable if one considers that the fundamental aim of the simplified calculation procedures is to provide a rapid estimate of ground eat transfer. Naser. S. Sanoussi. [22] presented a numerical simulation to determine the optimal layout and size of insulation for the building floor under different operational with geometrical parameters on the total heat loss from the building, the study confirmed that the vertical insulation decreases the total heat flow through the building floor more than that of the horizontal insulation configurations.

II. THE MODEL

The physical model under consideration is shown in Fig.2. The solution domain is the ground beneath the building through which the heat loss from the building foundation is transferred. The ground is represented by a semi-infinite two-dimensional solid with isotropic conductivity, k. It is assumed that the thermal properties of concrete slab need not to be taken into account explicitly, i.e., the semi-infinite solid is assumed to be homogenous. The ground is assumed to be an infinite periodic array of slabs, horizontally in the axial direction, as shown in Fig.2. The array axial spacing is equal to L starting from the middle plane of the building to the point where the axial heat transfer is vanished.

Vertically below the building the slab starts from the interfacing between the bottom of the building and the surface of the ground and ends at a plane of known temperature equals to the ground water table. This vertical spacing is equal to b. The ambient air temperature inside the building is T_i and the outside air temperature is T_o. The convective heat transfer coefficient inside the building is h_i and the convective heat transfer coefficient outside of the building is h_o. The water table temperature is assumed to be T_b , Due to symmetry only half of the building width is considered and is assumed to be equals to w. The heat is assumed to transfer mainly between the building foundation and the surrounding air.

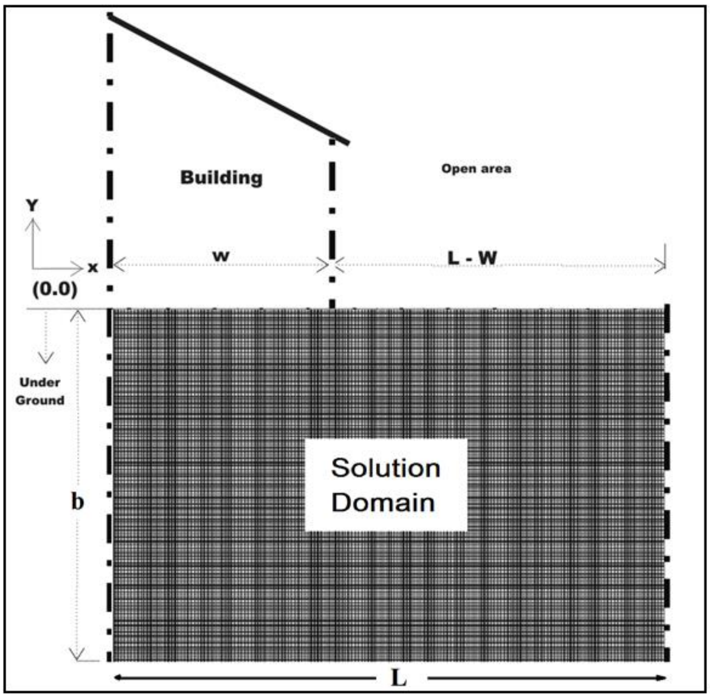

Fig.2 Coordinates and parameters of the problem

The mathematical model is represented by the conduction equation in two dimensional rectangular coordinates under steady state conditions and constant properties without heat generation.

The applicable conduction equation in dimensional form is:

$$\nabla^2 T(x, y) = 0. \tag{1}$$

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

The appropriate boundary conditions are:

$$\frac{\partial T}{\partial x} = 0 \qquad at \qquad x=0 \qquad , \ 0 \le y \le b \qquad (3)$$

$$\frac{\partial T}{\partial x} = 0 \qquad at \qquad x=L \qquad , \ 0 \le y \le b \qquad (4)$$

$$\frac{\partial T}{\partial y} = -\frac{h_i}{k}\left(T_i - T(x,0)\right) \qquad at \qquad 0 \le x \le w \ \& \ y=0 \qquad (5)$$

$$\frac{\partial T}{\partial y} = -\frac{h_o}{k}\left(T_o - T(x,0)\right) \qquad at \qquad w < x \le L \ \ \& \ \ y = 0 \qquad (6)$$

$$T = T_w \qquad at \qquad 0 \le x \le L \ \ \& \ \ y = b$$

The heat flux to or from the domain is calculated from the following equation:

$$q(x) = -k \left.\frac{\partial T}{\partial y}\right|_{y=0} \qquad (7)$$

III. SOLUTION PROCEDURE

The fluent software program used to find the results, it is a suite of programs that model systems in computational fluid dynamics (CFD). This includes flows in two- and three-dimensional geometries, and under a variety of conditions, also can supplies a graphical user interface, all of that with using Gambit program which is a preprocessor for modeling geometries, generating meshes and limiting the boundary condition

IV. RANGE OF PARAMETERS USED

The parameters covered in this study are selected from previous works to ensure that all possible practical values are covered in this investigation. Table (1) shows the suggested values of all parameters along with their users with the parameters in their normalized form as well as their covered ranges.

Table (1) the suggested and Range of Parameters Used

Parameter	Min.	Ref.	Max.	Ref.	used
L (m)	10	[17]	24	[10]	10
w (m)	5	[17]	9	[10]	5
b (m)	2	[18]	∞	[21]	2 :100
K (W/m.°K)	0.144	[19]	0.623	[19]	0.623
h_i (W/m^2.°K)	1.4	[19]	7.5	[19]	3
h_o (W/m^2.°K)	3	[19]	75	[19]	7.5 & 75
T_i (°C)	20	[20]	23.5	[17]	23
T_b (°C)	4.4	[10]	11	[18]	10
T_o (°C)	-7	[10]	40	[19]	-5 & 40

V. RESULT AND DISCUSSION

○ *Effect of the Water Table Depth on the heat flux through Building floor*

According to the field measurements there are three boundary temperatures having an effect on the temperature distribution underneath a slab-on-ground: the internal, the external and the table water temperatures. A two-dimensional model of a house has been implemented in order to find the thermal behavior of the floor with contact with ground and outside properties, plotted temperatures presented the distribution along the domain at maximum and minimum temperature also shows the effect of water table variable from 2m depth to 100m from the middle of the building. The most effect of the water table is higher nearest the ground and it can be seen in Fig.3. that at minimum temperature (-5C°) the total heat flux will be almost stable at 10m depth to be the maximum effective level, while in Fig.4. at temperature of (40 °C), water table level effected until the depth of 60m where that specially at summer season.

○ *Temperature distribution in the ground area:*

At soil depths greater than 50 meters below the surface, the soil temperature is relatively constant, and corresponds roughly to the water temperature measured in groundwater wells 2 to 30 meters deep. This is referred to as the “mean earth temperature, all of that will be shown in the next temperature contour figures from 5 to 16 and these results presented with at different conditions in terms of internal convection effect (h_i), external convection effect (h_o) and outside temperature (T_o) with the depth of (b).

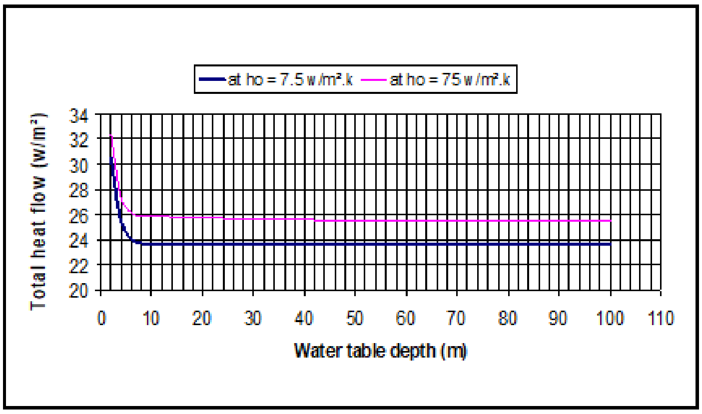

Fig.3. Effect of water table level on the heat flow from building floor at (T_o = -5ºC)

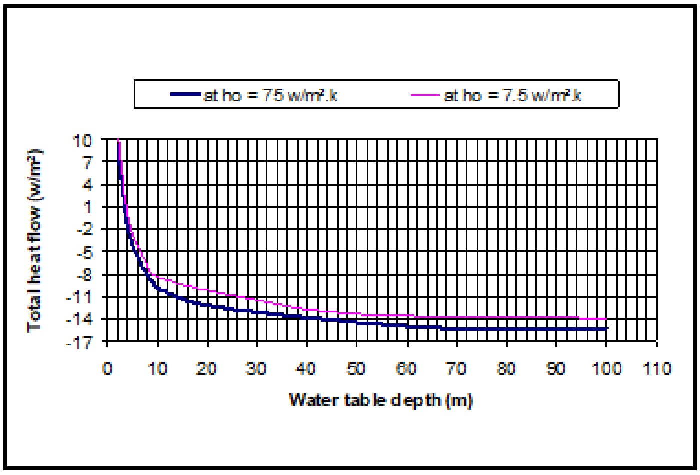

Fig.4. Effect of water table level on the heat flow from building floor at (T_o = 40ºC)

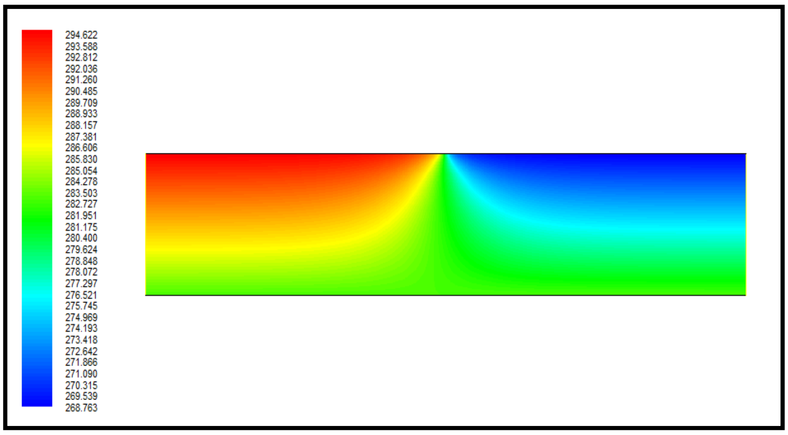

Fig. 5. Temperature contours at (T_o = -5°C), (b = 2m) and (h_o = 7.5w/m^{2}K)

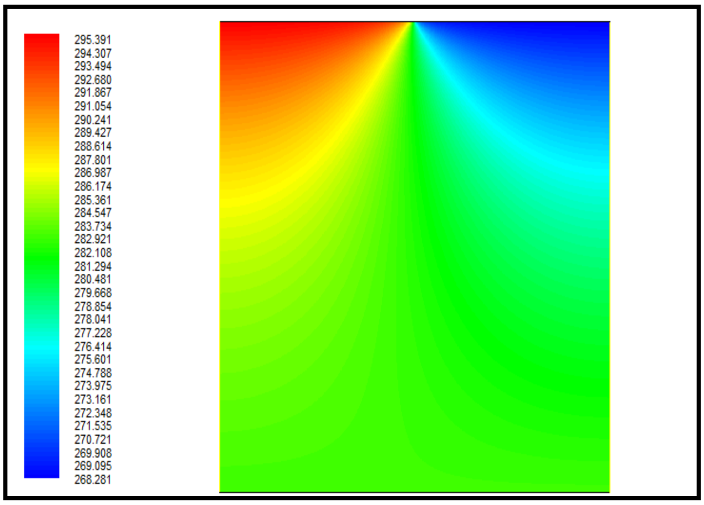

Fig. 6. Temperature contours at (T_o = -5°C), (b = 10m) and (h_o = 7.5w/m^{2}K)

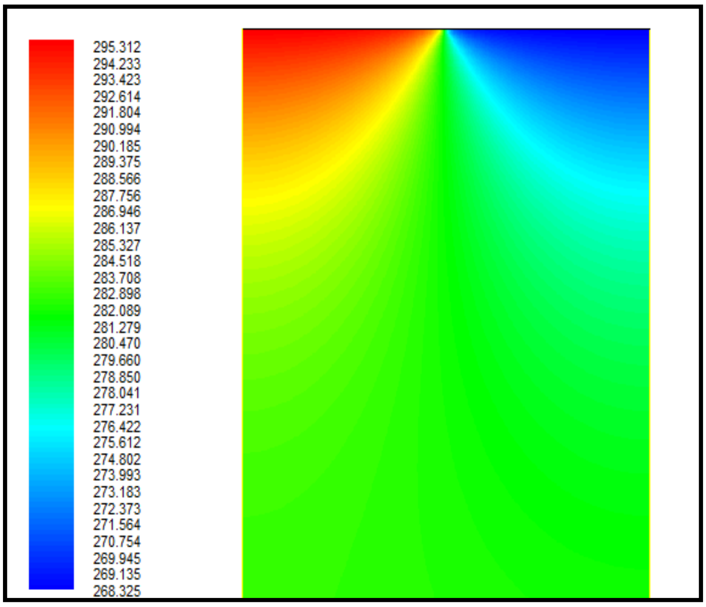

Fig.7. Temperature contours at (T_o = -5°C), (b = 100m) and (h_o = 7.5w/m^{2}K)

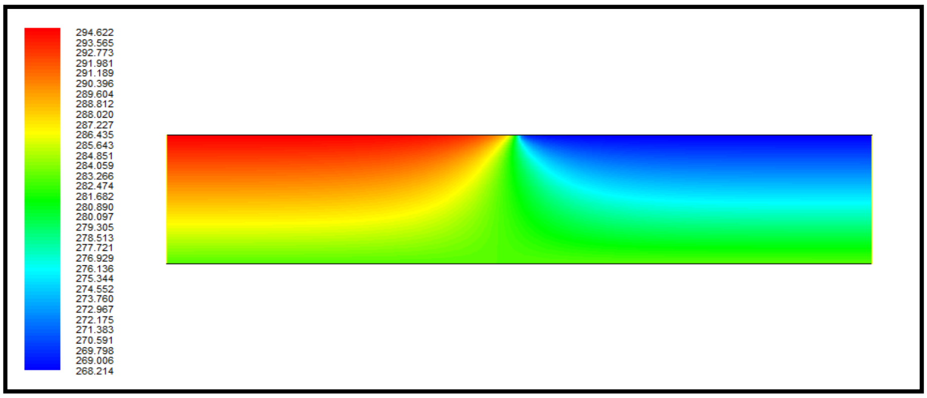

Fig.8. Temperature contours at (T_o = -5°C), (b = 2m) and (h_o = 75w/m^{2}K)

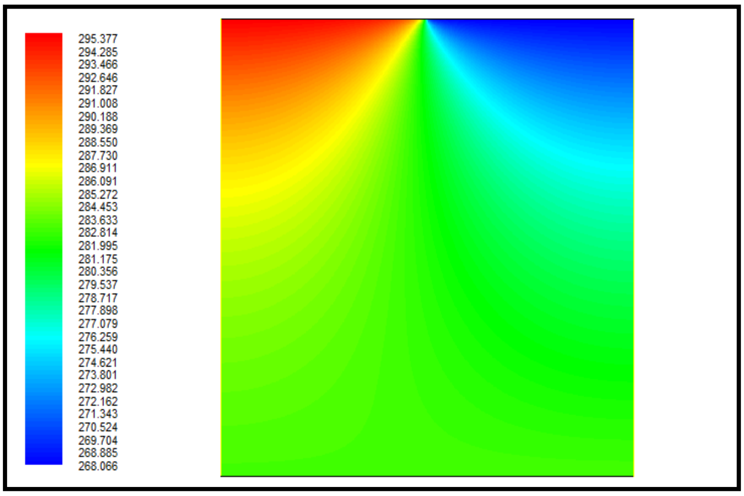

Fig.9. Temperature contours at (T_o = -5°C), (b = 10m) and (h_o = 75w/m^{2}K)

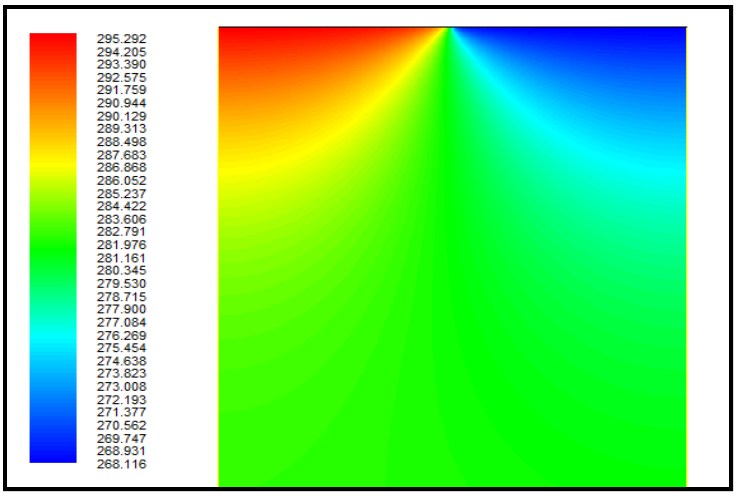

Fig.10. Temperature contours at (T_o = -5°C), (b = 100m) and (h_o = 75w/m^{2}K)

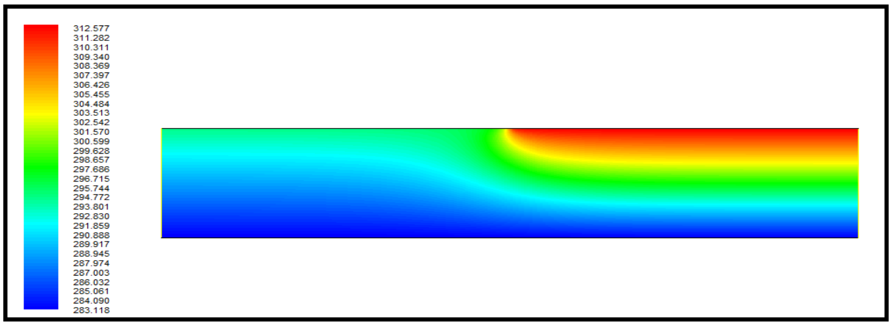

Fig.11. Temperature contours at (T_o = 40°C), (b = 2m) and (h_o = 75w/m^{2}K)

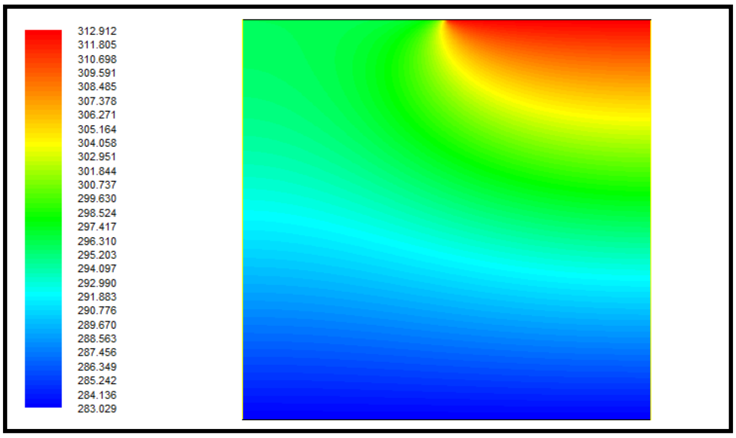

Fig.12. Temperature contours at (T_o = 40°C), (b = 10m) and (h_o = 75w/m^{2}K)

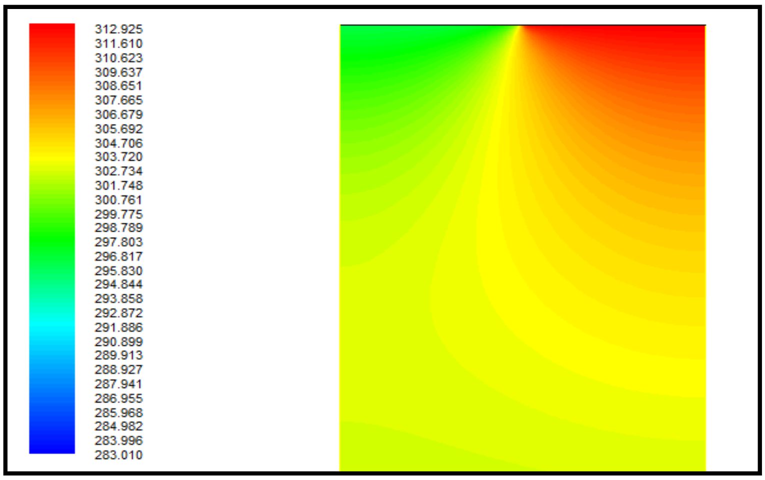

Fig.13. Temperature contours at (T_o = 40°C), (b = 100m) and (h_o = 75w/m^{2}K)

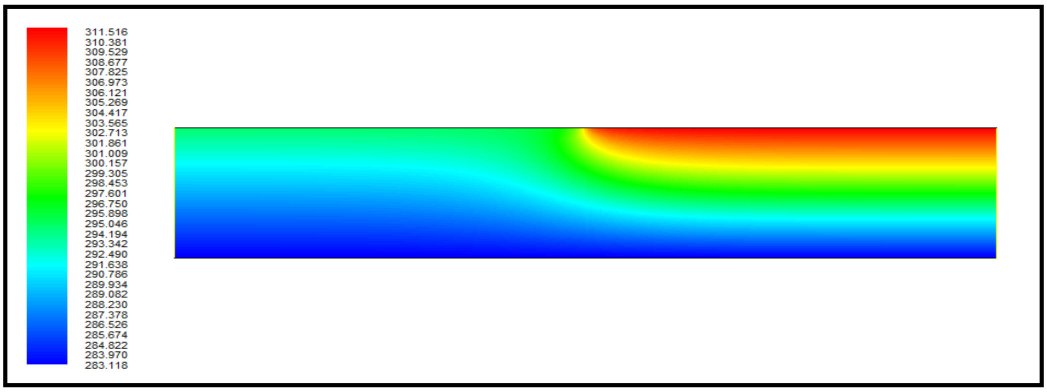

Fig.14. Temperature contours at (T_o = 40^{o}C), (b = 2m) and (h_o = 7.5w/m^{2}K)

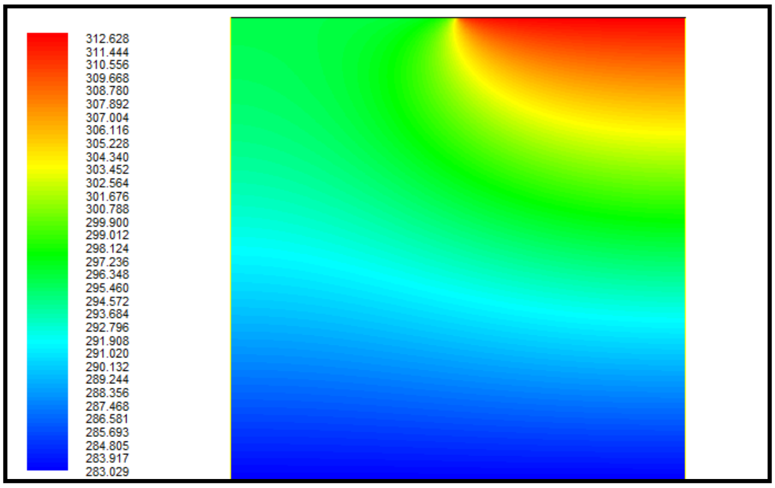

Fig.15. Temperature contours at (T_o = 40^{o}C), (b = 10m) and (h_o = 7.5w/m^{2}K)

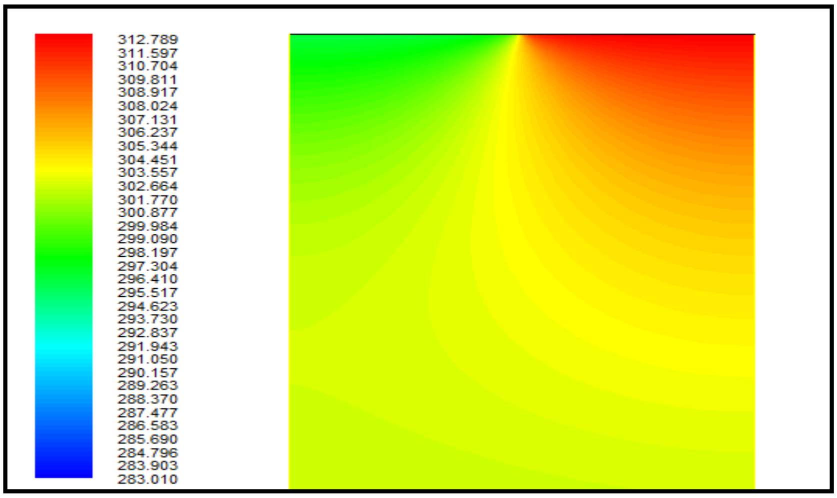

Fig.16. Temperature contours at (T_o = 40^{o}C), (b = 100m) and (h_o = 7.5w/m^{2}K)

VI. Conclusions

Steady-state heat conduction equation analyses were performed for a two-dimensional earth-contact by using fluent software and was analyzed for water table depths ranging from 2m to 100m, the results obtained showed that most of the heat flow through building floor occurs through the region lying close to the edge of the building walls as the results showed a significant effect of the water table depth on the heat flow through building floor at a depth less than 30meters with the change of operational standards. The effect of the convective heat transfer coefficient outside of the building with different temperature are not that effective and accordingly fixed at properly selected values, where the temperature different between outside and inside the building is the main parameter that effect on the total surface heat flux along building and total heat flux to the ground increased significantly with decreasing ground water table depth, It is recognized that the results and the range of analysis presented and provides first indication of the significance of this particular aspect for the ground heat transfer problem.

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