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Impact of Building Architecture and the Height of the Chimney on the Atmospheric Chimney Function

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ABSTRACT
In this paper the behavior of masonry chimneys connected to gas-fueled appliances equipped with atmospheric burners are examined through numerical modeling. Two important factors, i.e. the height of the chimney and the position of the chimney, impacts on various building architectures have been studied. Studied chimney parameters included generated suction, velocity and temperature of the flue gases at the outlet.Thus, the chimney connected to the household gas-fueled heater in different lengths and performance of conventional construction is studied.To ensure the accuracy of the results a laser thermometer was used to measure the temperature of different parts of the geometry and the results were compared with numerical solutions. The results show that permissible height of the chimney in the range of 3 to 15 m and locating the chimney on the building components influences the chimney suction to 128% and 70%, respectively. Also, the simultaneous impact of the height and the operation of chimney inhigh chimneys led to a sharp reduction in the temperature of the combustion products with the risks ofdew formation. Increasing the height of the chimney increased the speed to 40 % and effectiveness of implementing reduced it to 33%. Higher chimney outlet speed is important to overcome the wind current at the exit of the chimney.
Keywords*: Chimney, Natural suction, Numerical simulation, Gas heater, Building architecture*

INTRODUCTION

Today, with more extensive use of natural gas in the domestic gas appliances have become more common with some risks associated with it. Lack of attention to the behavior of the chimney in different buildings architectures has caused a lot of problems. Promoting the use of local heating and instead of central heating and neglecting the chimney functional changes connected to appliances in various operations along with other internal and external factors can cause problems in the discharge of hazardous products of combustion. With a better understanding of the behavior of the chimneys connected to the appliances and issuance of simple safety recommendations can prevent gas poisoning Injuries caused by it. The phenomenon of combustion process in the living environment is one of the most risky debates in installations. So, the design of safe passage of combustion products to the outdoors is important. Chimney connected to atmospheric burners in local domestic heating systems transfer combustion products to the outer space.

Various parameters affect on the performance of the chimney connected to an atmospheric burner,but finding the chimney effect acceptability of a particular factor may have contributed to its design.Studying various factors affecting the permissible height of the chimney in vitro is difficult and costly; therefore, various modes simulation can help the designer choose the best chimney connected to a gas appliance.The most important height, factors affecting the atmospheric chimney performance include the chimney height and the chimney shell heat transfer to outer space.Atmospheric chimney behavior is entirely dependent on the performance of the appliance connected to it and its function environment. Therefore, the most common appliance used in residential buildings, namely gas-fueled heater is used for the chimney setup. Studied heater capacity is 8000 Kcal per hour. The reason to choose this capacity is the commonality of this type of appliance.

The main parts of a gas heater are:

- Burner: where complete mixing of air and fuel happens and combustion flame is formed in the output level
- Furnaces: part of the heater in contact with the flame and with a higher temperature
- The surface of the furnace in contact with the residents hand during the use with the lower temperature

The heat generated is first appears by the combustion gases increased temperature and a small amount of radiation of the flame and then the gases transferred to the body of gas heater during the motion toward the chimney in all three forms of heat transfer and after heating the surrounding air heat the house. Chimney is a circular or rectangular conduit to conduct combustion gases in the combustion chamber out of the building. Chimney is made with various sections, such as circle, square, and rectangle. Circular profile is best for chimney. The major chimney parameters that must be monitored and reviewed include suction generated at both ends of the chimney as flow drives and speed and temperature of the combustion products in the chimney outlet.

Higher rate of output can help overcoming the unfavorable outer factors such as wind and higher temperature at the outlet is important to prevent dew formation.

Hauland and Sparrow [1] conducted the numerical solution of chimney wall insulation and a heat flow from heat source. Dias Delgado et al (1996) studied the analysis method and forecasts of ventilation rate, temperature and the chimney inside pressure, which is influenced by thermal buoyancy and wind flow. They examined Masonry chimney efficiency with energy and momentum equations as natural ventilators as well as numerical solutions. The results were the important relationship between heat and momentum variables and the chimney essential role in the process of ventilation [2]. C. Cortes et al (1998) did numerical and experimental measurements of temperature of the exhaust gases from combustion and chimney outlet [3].Oronzio Manca et al (2002) conducted laboratory investigations on the flow inside of a chimney. They studied heat transfer in a chimney channel with a changed cross section [4].Oscar Fariaset al. (2007) studied suction in a gas-fueled shared masonry chimney theoretically and in vitro.They studied a shared masonry chimney channel in different levels of a building and reviewed the effect of heat capacity, chimney height, and chimney height above sea level [5].Siamak Hossein Pour et al found the best barriers in a 3-meter chimney inlet with appropriate barriers placed in the heater furnace and the hot exhaust gases flow path to increase efficiency [6].Wu-Shung Fuet al studied natural relocation in three conical numerically without regarding Boussinesq approximation [7].This study attempted to use the experiences and results of previous studies on the localization of chimneys in accordance with current standards and today's buildings architectures.

METHODS

Since the objective of this research is to obtain the parameters of the chimney in various heights and operations, heat furnace connected to the chimney geometric details are ignored and simplified geometry of the furnace with dimensions close to that of the actual furnace is used according to Figure 1. Room temperature of 22 ° C and outside room temperature of zero ° C are assumed. Surface heat transfer coefficient with the vertical and horizontal surface of 9 and 11 watts per cubic meter Kelvin is considered, respectively [8]. Due to the relatively high temperature of furnace radiation heat transfer in the environment is considered in the calculation with on-slip condition on all walls.

At the inlet of fresh air to the pressure inlet boundary condition and at the outlet the pressure outlet boundary condition at are applied, respectively. Fireplace acts as a chimney driver, so there is no need for details of the combustion processes taking place in it, therefore, heaters flame is modeled as a boundary condition with fixed heat flux in dimensional equal to that of the actual level of flame, the heat flux is calculated as follows:

$$8000\text{kca}\,\mathrm{l/hr} = 9304\text{watt} \rightarrow \frac{\dot{Q}}{A} = \frac{9304}{.015 \times .55} = 1127758\ \mathrm{w/m^2}$$

Attempts have been made to gain the maximum coordination with actual operational conditions and performance standards in the buildings in the design of the model chimneys geometry.Thus, an inner diameter of 10 cm was chosen for chimney [9].Since in the current building architecture accessto the vertical route of chimney is placed on a 90-degree bend,thus, as shown in Figure 2, assuming the chimney direct connection to the heater inlet with a 25 cm with a bend of 90 degrees is used.

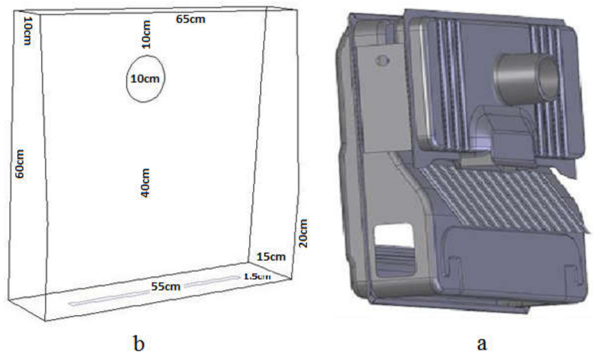

Figure 1 (a) Real heater furnace, (b) Studied simplified model

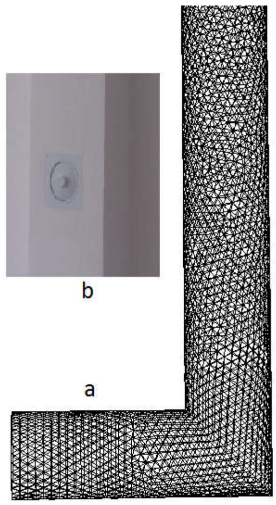

Figure 2 (a) studied chimney mesh and chimney inlet view, (b) actual operation of chimney inlet

RESULT

The governing equations and their numerical solution

The governing equations include the conservation of mass equations,Momentum and energy (Equation 1 to 3) that can be solved by Fluent software in the finite volume method of numerical analysis in three-dimensional coordinates [10].

$$\overline{\nabla}.(\overline{V}) = 0 \qquad (1)$$
$$\overline{\nabla}.(\rho\overline{V}\,\overline{V}) = -\overline{\nabla}\mathrm{P} + \overline{\nabla}.(\mu\overline{\nabla}\mathrm{V}) \qquad (2)$$
$$\overline{\nabla}.\left(\rho(e+\frac{V^2}{2})\overline{V}\right) = -\overline{\nabla}(\mathrm{k}\overline{\nabla}T) + q_r \qquad (3)$$

Where ρthe density, $\overline{\nabla}$speed vector, Ppressure, μviscosity coefficient, ethe internal energy per unit mass, kgas thermal conductivity and $q_r$heat transfer by radiation, respectively. The governing equations have been solved using Fluent software and the finite volume method of numerical analysis and the method of separation solver. The SIMPEL method was used in Momentum equations and conservation of mass equations. After reviewing various options1×10^{-6}convergence criterion for radiation and energy AND $1 \times 10^{-4}$for the other equations were applied, respectively. Under Relaxation factors shown in Table 1 were used to control the computed values, also an ideal gas model was used to simulate the density.

Table 1 Under Relaxation factors

Pressure	momentum	energy	Discrete Ordinations
0.3	0.4	0.9	0.95

Because all equations are solved simultaneously, to determine the independent solutions, meshing of suction three parameters (pressure difference between ends of the chimney),the temperature of the chimney exhaust and outlet gas speeds were examined as shown in graph in Figures 3 to 5. Due to slower convergence of temperature, the number of meshes for 3-meter chimney after the outlet temperature constant was selected equal to 90,000 nodes.

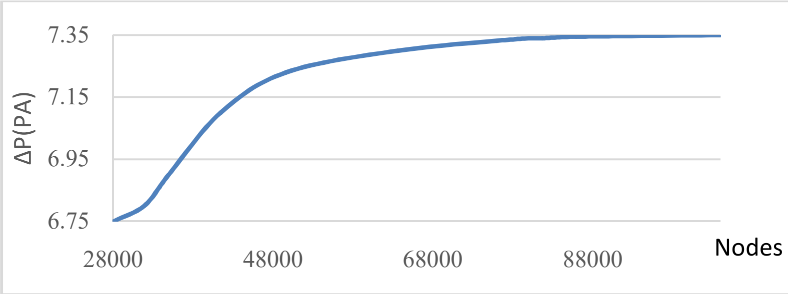

Figure 3 Effect of different mesh on 3-meter chimney suction

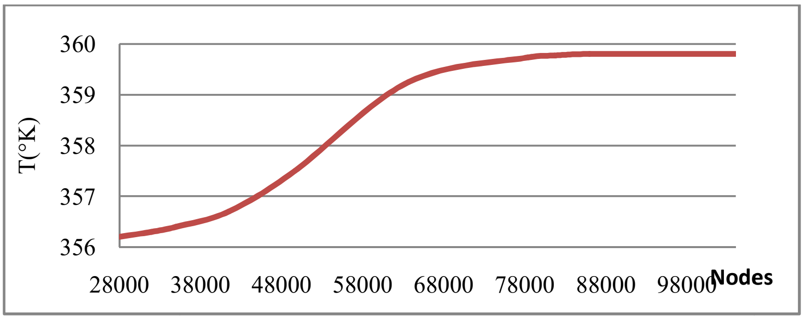

Figure 4 Effect of different mesh on 3-meter chimney exhaust gas temperature

After the numerical solution of the furnace connected to a chimney with 3-meter vertical path with a perfectly smooth internal surface and thermal insulation in sea level,under the boundary conditions assumed, furnace temperature contour and furnace- chimney pressure contour are as shown in Figure 6.

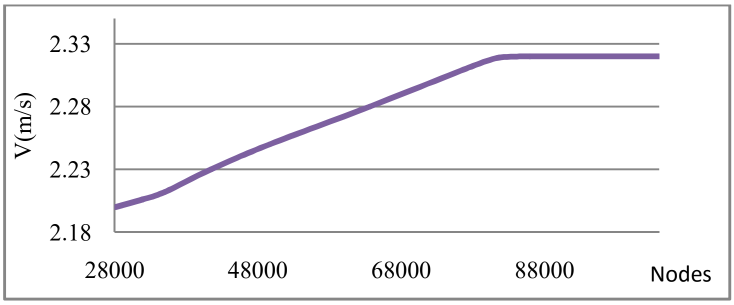

Figure 5 Effect of different mesh on 3-meter chimney emissions speed

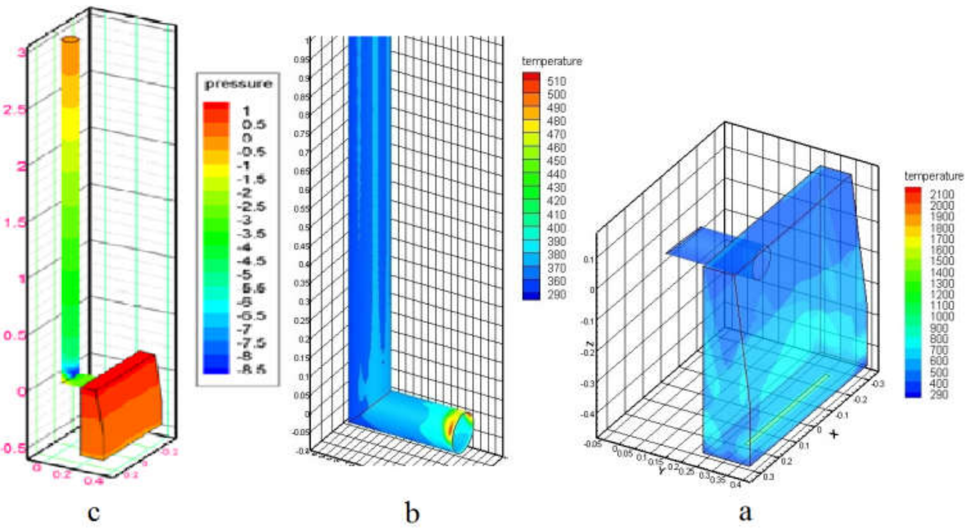

Figure (6) a) furnace heater temperature contour, b) the first one -meter of chimney temperature contour, c) contour of the furnace and chimney pressure at sea level with a smooth internal surface

To ensure the accuracy of the results obtained the temperature of three different points of a 3-meter furnace and chimney was measured using laser thermometer according to Figure 7, and is compared with numerical solutions in Table 2

Table 2 comparison between the results of numerical and measured values

	Point 1	Point 2	Point 3
Numerical Solution	88°C	173°C	255°C
Laboratory work	84°C	161°C	231°C
% Difference	5	7	11

Point 1: The temperature of the first one -meter of chimney
Point 2: The temperature of the highest point of furnace wall
Point 3: The furnace temperature 15 cm above the flame

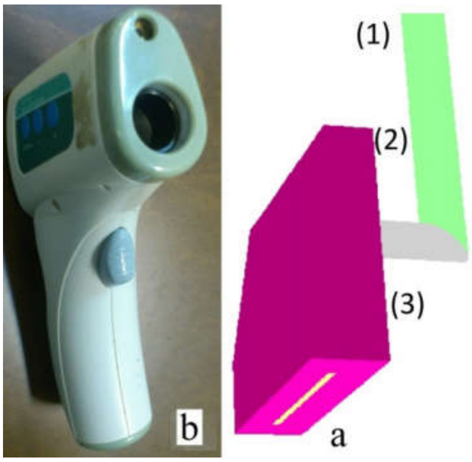

Figure (7) (a) the measured position; (b) used laser thermometer

Chimney types components in buildings

Exhaust heat transfer rate with the outside world varies depending on the location of the chimney components in building. This studydiscussed5 most common types of chimney components in modern buildings according to Figure 8. Figures 9 to 11 show operation details of the chimneys.

Figure (8) different types of operation cases for the chimney in the building

Table 3 shows compound wall heat transfer coefficient using equations 4 and 5, and Section 19, the National Building Regulations calculated data. [8]. Average heat transfer coefficient and the average temperature of the free flow in regard to chimney heat transfer with inside the building and outside the building was calculated.

$$R_{wall} = R_1 + R_2 + \dots R_i + \dots + R_n \left[\frac{m^2K}{w}\right] \quad (4)$$

$$R_{wall} = {d_1}/{\lambda_1} + {d_2}/{\lambda_2} + \dots {d_i}/{\lambda_i} + \dots + {d_n}/{\lambda_n}$$

$$U = \frac{1}{R}\left[\frac{w}{m^2K}\right] \quad (5)$$

Table (3) the average heat transfer coefficient and the average temperature of free flow of different operations

operation	Average heat transfer coefficient $\left[\frac{w}{m^2K}\right]$	The average temperature free flow $T_\infty[K]$
Type 1	11.30	278.5
Type 2	9.30	278.5
Type 3	4.82	289.5
Type 4	2.84	295
Type 5	1.32	284

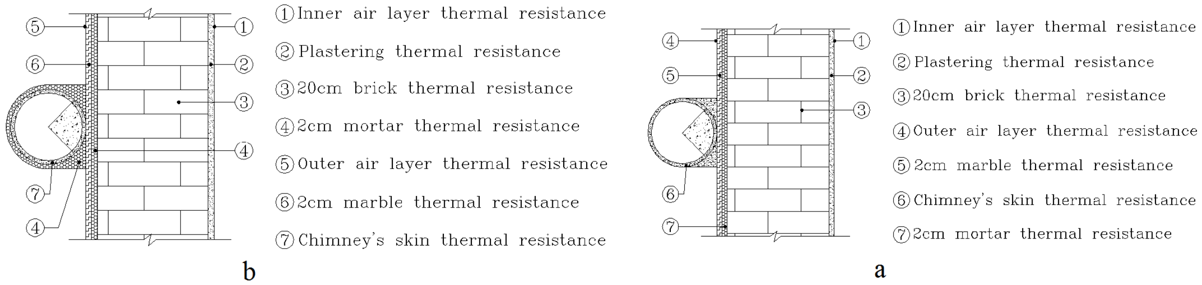

Figure 9 A) operation details chimney type 1, B) operation details chimney type 2

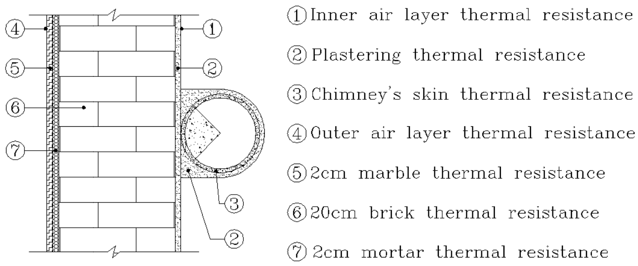

Figure 10 operation details chimney type 3

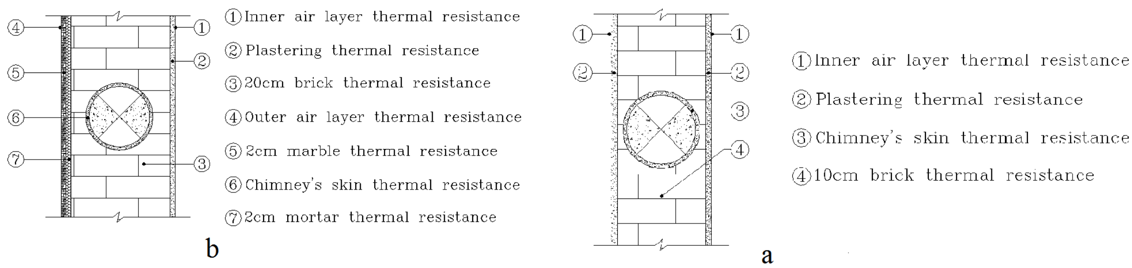

Figure 11 (A) operation details chimney type 4, B) operation details chimney type 5

The impact of height on chimney function

By increasing the length of the vertical height of the chimney in the permitted range and given the smooth and insulated chimney walls,the suction generated, the average rate of emissions of chimney, average rate of energy loss along the exhaust emissions of chimney are shown in diagrams of Fig. 12, 13 and 14.According to Section 17 the National Building Regulations height limit of atmospheric building chimneys is 3 to 15 m [9].The differences between then numerically calculated suction values ans experimental study values in Figure 12 are different cross-section of the chimney and the device connected to it in the study.The temperature of the outlet gases do not change due to the insulation.

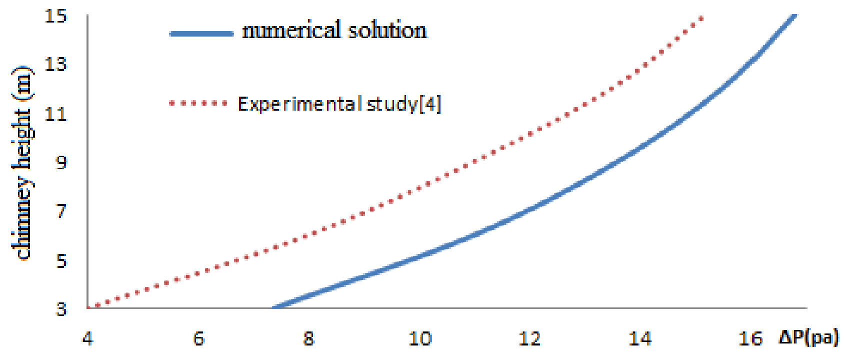

Figure 12 the effect of height on the suction chimney insulation

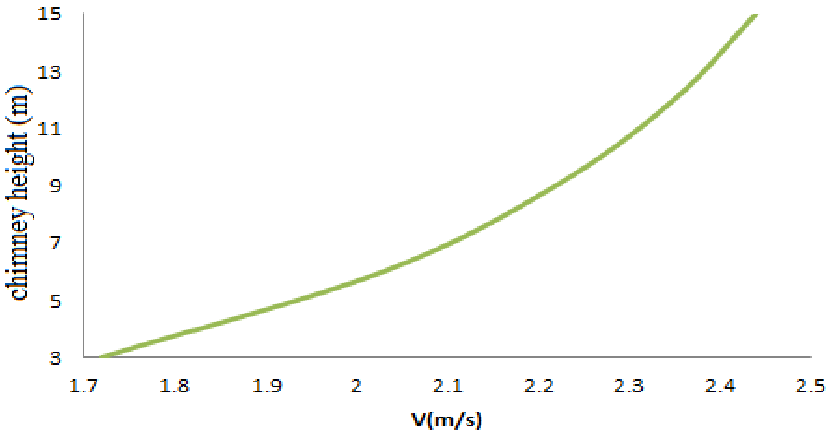

Figure (13) the effect of height on the average speed of the exhaust chimney insulation

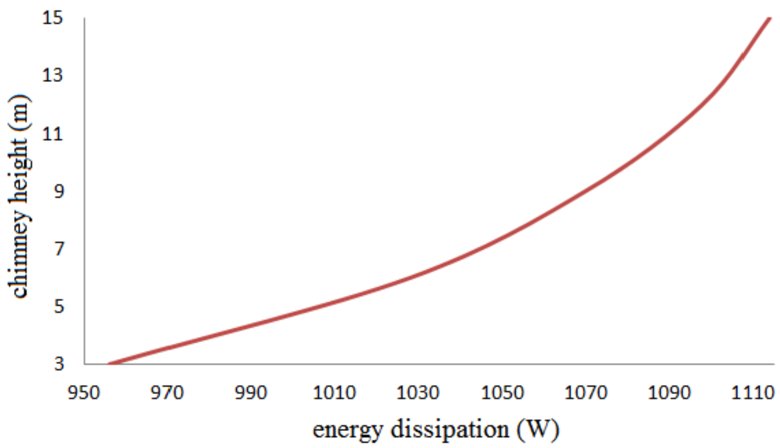

Figure (14) the effect height on the rate of energy dissipation along the chimney exhaust

The operation type impact on chimney function

To examine the impact of operation, the problem was solved with boundary conditions (Table 3) in the range of allowable height lengths. Chimney center line in diagrams drawn is a line that starts in the cross section of the center line of horizontal and vertical lines up to the chimney outlet opening. Distribution of pressure, speed and temperature of the center line in 15- meter chimney in different operations are according to the diagrams of Fig. 15, 16 and17, respectively. According to Figure 15, parts of chimneys type 1 and type 2 do not involve in suction generation.

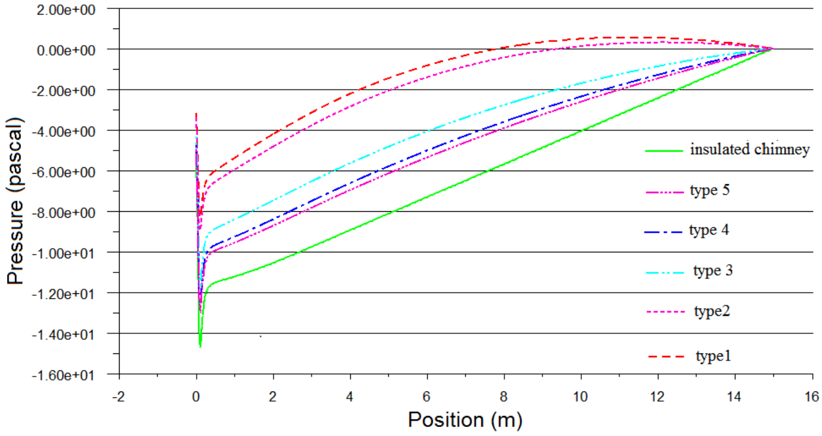

Figure (15) Central line pressure in 15 meters chimney in different operations

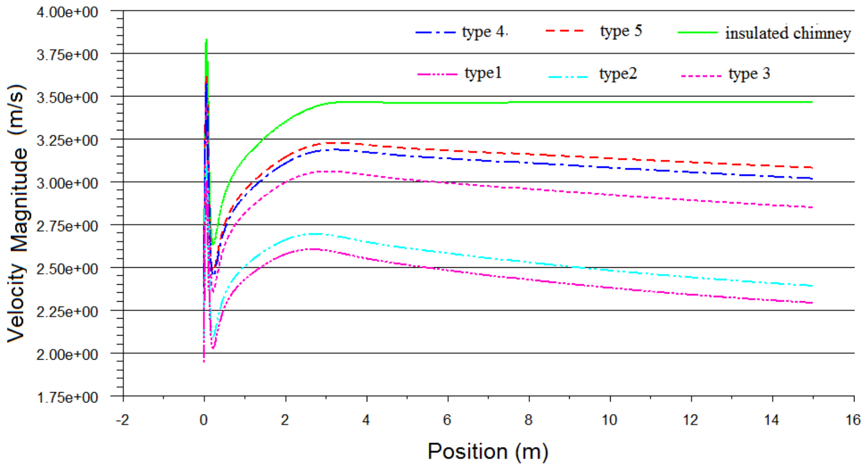

Figure (16) Central line speed in the 15-meter chimney in different operations

We will examine more closely the type 1 chimney because it shows the maximum suction reduction. Pressure, speed and temperature of the gas distribution on central line with different heights are shown in Figure 18, Figure 19 and Figure 20, respectively. Figure 21 compares the suction increases with increasing height of the chimney at various operations.

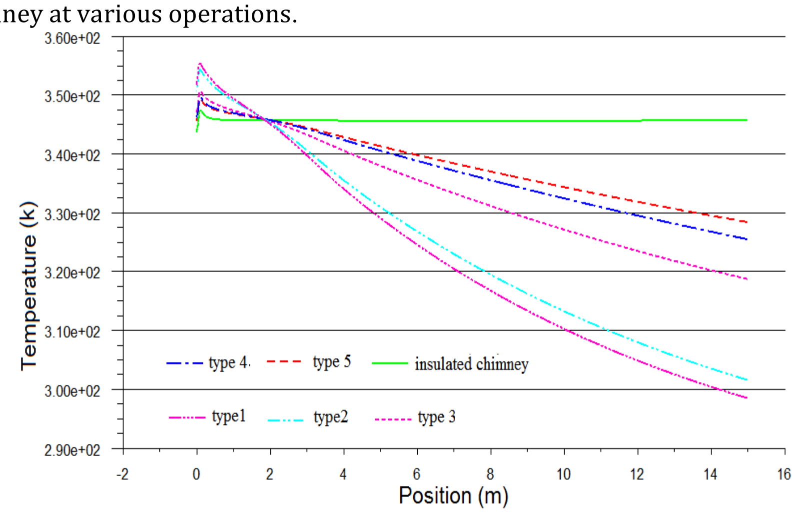

Figure (17) the temperature in central line15 meter chimney in different operations

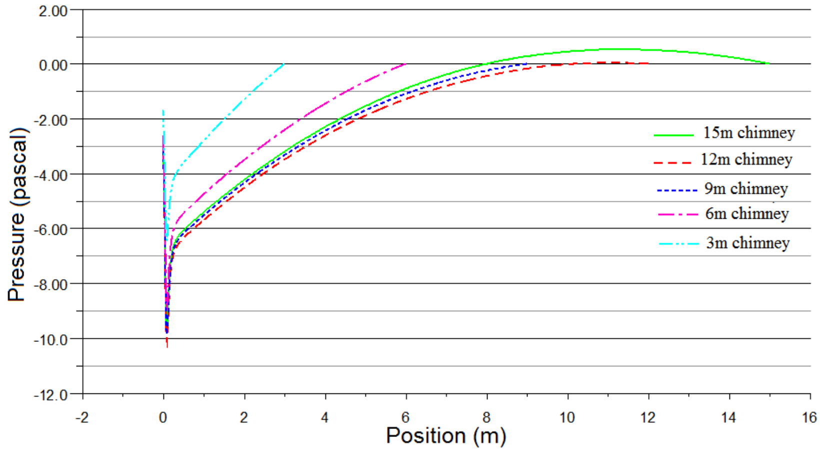

Figure (18) Central line pressure type 1 chimney with different heights

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DISCUSSION AND CONCLUSIONS
This study investigated the influence of chimney height and various chimney operations in buildings on the suction, speed and average temperature of the combustion products parameters and compared them with insulated chimney.

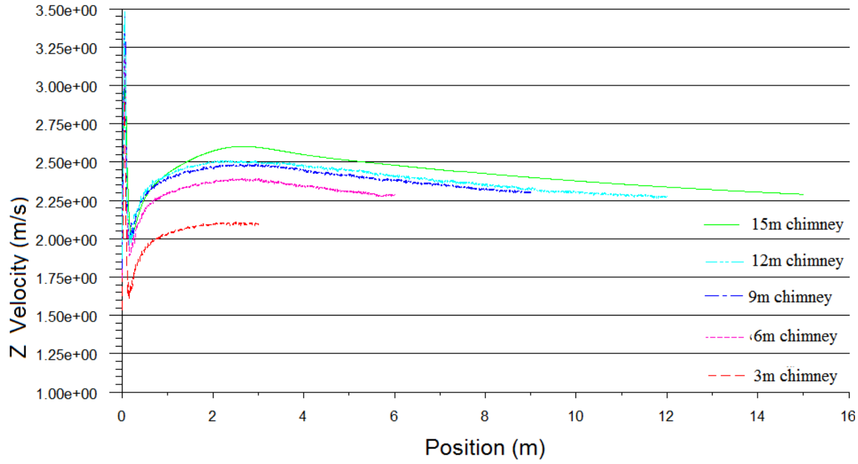

Figure (19) Central line speed type 1 chimney with different heights

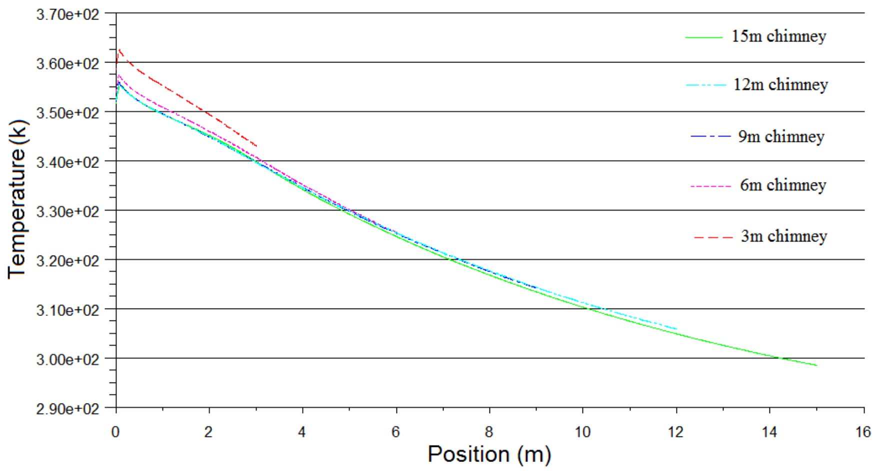

Figure (20) the temperature of the flue type 1 chimney with different heights

This is done by solving the boundary conditions corresponding to the study operations for the geometry of the furnace and chimney connected to it in the range of 3 to 15 meters height. The results show that the chimney height of 3 to 15 meters (Table 4) affects the functioning of the chimney. I.e. with the higher height of the chimney we face with a large increase in the suction, increase in the average rate of the gases in the exhaust and a slight increase in the outlet energy losses.

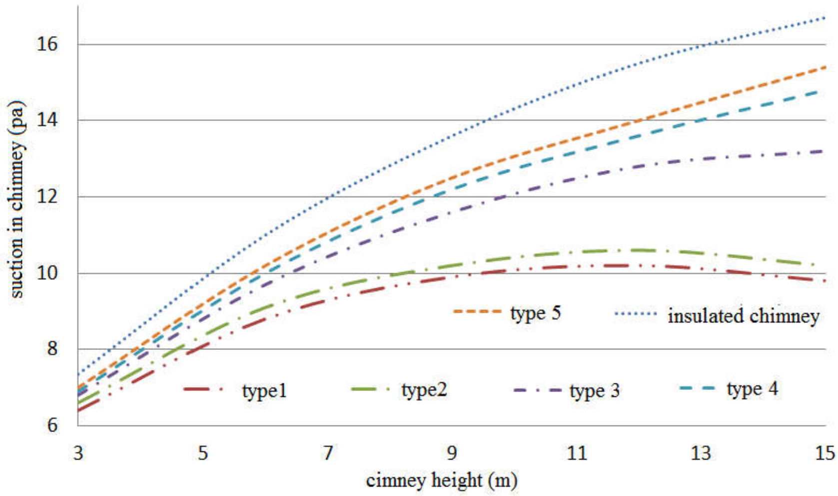

Figure (21) suction in the chimney with different lengths and different operation

Tables 4 compare the heat insulation parameters of the 3-meter and 15-meter chimney heights

	suction (pa)	Average rate of emissions (m/s)	The energy dissipation with exhust gas (w)
Standard 3-meter chimney	7.35	1.72	956
Standard 15-meter chimney	16.8	2.44	1114
Increase Percentage	128%	42%	16%

According to figure 15, in type 1 and 2 operations, parts of the chimney ends are not involved in the creation of suction. This is because the density of the combustion products is closer to the density of outside air. In types 3, 4 and 5 operations in the studied height range, suction increase slope is positive and all chimney length involves in creating suction. The suction reduction, speed and average gas temperature in chimney outlet with various implantation of a15-meter chimney is compared to insulating state in Table 5.A closer look at the results shows that the suction generated in the chimney creates a small pressure difference between the chimney ends that at best is removed with a less than a 15 grams barrier.So, in practice the exercise of all other factors affecting the chimney along with affecting external factors on the chimney we will face with risky situations. Among the proposed ways to stay away from dangerous situations of local gas-fueled heating appliances in modern residential buildings is creating the culture for the use of central heating with more and more closely monitoring of designing of chimney building processes.

Table (5) the parameters of a 15-meter chimney in various executive positions

	Suction (pa)	decrease Percentage compared to the insulation	average temperature of the exhaust gases (m/s)	decrease Percentage compared to the insulation	average temperature of the exhaust gases (K)	decrease Percentage compared to the insulation
Insulated chimney	16.7	0	3.45	0	346	0
Chimney type 5	15.4	8	3.1	10	328	5
chimney Type 4	14.8	11	3.05	12	326	6
Chimney type 3	13.2	21	3.85	17	318	8
Chimney type 2	10.2	39	2.35	32	302	13
Chimney type 1	9.8	41	2.3	33	298	14

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