SIMULATION OF NATURAL GAS SAVING THROUGH FOAM LIGHTWEIGHT CONCRETE UTILIZATION IN RESIDENTIAL BUILDINGS

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ABSTRACT
Heat loss through walls in houses is remarkable and it shares about 25% of total loss. Utilizing Foam Lightweight Concrete (FLC) block in walls may lead to reduction in both gas consumption and greenhouse gas emissions. This is due to heat insulation property of the block and consequently less energy consumption. The main objective of this research was to investigate how FLC block can save natural gas usage within building envelop. A typical residential building was simulated for pressed brick, terra-cotta block, 3D panel, and FLC block by utilizing Behsazan software. Afterwards, building gas consumption and relevant carbon dioxide emissions were compared for abovementioned wall materials, while the building area was constant and its height was variable. Results showed that annual gas reduction attributed to utilizing FLC block walls with different heights varies from 25.7% to 30.6% and from 18.5% to 23.3% in comparison with pressed brick and terra-cotta block walls, respectively. This reduction for 3D panel walls was about 4.6%. Moreover, CO_2 emission reduction depending on the number of floors for FLC block walls with pressed brick, terra-cotta block, and 3D panel walls were equal to 20.8 to 24, 15 to 18.3, and 3.4 to 3.8 kg CO_2/m^2, respectively.

Key words*:* Foam lightweight concrete (FLC); Thermal transmittance; Gas consumption; Building height Carbon dioxide emission;

INTRODUCTION
Producing and utilizing different kinds of lightweight concrete have a history of about 50 years in the world (MOE, 2007). In recent years, increasing population density in big cities as well as lack of living space have drawn attention of industry to high-rise buildings construction in Iran. However, their heavy weight is by far the most important problem of these buildings which may result in intensified earthquake in design considerations. Therefore, utilizing light weight building materials in construction can minimize the magnitude and destructive impact of earthquake force on such buildings. On the other hand, 64% of supplied natural gas in Iran is consumed in residential and commercial buildings, which leads to 30% of the total carbon dioxide emissions (MOE, 2007).

Foam Lightweight Concrete (FLC) block due to versatile properties such as: i) lightness which causes significant decrease in earthquake force, building column, and foundation dimensions as well as construction duration, and ii) low thermal conductivity causing reduction in fossil fuel usage and respective greenhouse gas emissions costs,

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can be a viable and promising alternative to other traditional building materials. FLC is classified as concrete in which air voids are entrapped in cement mortar (Narimanian and Ramamurthy, 2000). As a result, a porous medium including air bubbles with 0.1 to 1 millimeter in diameter size is made (Neville and Brooks, 1990). This concrete is manufactured in different shapes such as precast block and in-situ concrete with a wide range of densities (300-1800 kg/m^3) as well as different applications (filler in roofs, façade of buildings, thermal and acoustic insulation). FLC is made from Portland cement, dune sand, water and foaming agent (with no need for autoclaving), (Maleki, 2005).

Recent national researchers have highlighted different properties of light-weight concrete such as low density, low thermal conductivity, high fire resistance and high acoustic insulation in comparison with other common used materials such as pressed brick, terra-cotta block, and normal-weight concrete. Moreover, thermal resistance (R-value) and annual energy saving in a typical external wall constructed of different kinds of light materials (lightweight aggregate concrete and polystyrene block) have been calculated and contrasted with the results of pressed brick, terra-cotta block, and normal weight concrete walls in supplementary investigations. The results have shown that R-value of lightweight aggregate and polystyrene walls is equal to 0.96, 0.83, and 0.91m^2K/W, respectively. Besides, the weight of these walls for a thickness of 15cm is 132, 145, and 119 kg/m^2, respectively (Emdadi *et al*., 2003). Thermal resistance of pressed brick, terra-cotta block, and normal weight concrete walls is 0.43, 0.617, and 0.417 m^2K/W, respectively and the weight of these walls is about 253, 274, and 274 kg/m^2, respectively. Finally, utilizing light-weight materials in walls of two-story residential building (1200m^2) leads to an average of 240 m^3/year gas saving (Emdadi *et al*., 2003). Also, the same calculations have been done for a one-story residential building with area of 150 m^2. R-value for three different wall materials (pressed brick (20 cm), terra-cotta block (20 cm), and FLC block (16 cm)) is equal to 0.46, 0.67, and 1.05m^2K/W, respectively. Annual energy saving cost of building with FLC walls compared to pressed brick and terra-cotta block walls is 45% and 35%, respectively (Hashemi, 2003).

In another study, the effects of i) different thermal insulations such as glass-wool utilizing in external walls and roof and ii) various types of glasses and sizes of windows on energy consumption rate of a three-story residential building have been investigated using ASEAM software in Tehran. Utilizing 5 cm glass-wool insulation in 21 cm pressed brick face walls caused 5% reduction in annual gas consumption of the residential building. This reduction rate for 30 cm barrel vault roof was about 3% as a result of using 2.5 cm glass-wool insulation. Utilizing double glazing window instead of single glazing window led to 9.4% reduction in annual energy consumption of the house. Also, reducing the area of windows from 2.3 m^2 to 1 m^2 resulted in 6.8% energy saving per year (Arabzadeh and Kazemzadeh, 2005).

The main objective of this research was to investigate the annual gas consumption and consequently carbon dioxide emissions rate variations through utilizing different wall materials such as FLC block, pressed brick, terra-cotta block, and 3D panel in a typical residential building which had constant area (470 m^2) and variable heights (5, 10, 13, 17, 20 floors).

Thermal insulation capability of FLC block, which is 4 to 6 times more than that in pressed brick, is a function of density and size of pores. It increases when the 2 abovementioned parameters decrease (Narimanian and Ramamurthy, 2000).

Utilization of FLC block walls has other advantages in addition to significant decrease in energy consumption and weight of the buildings as follows(Saimi, 2005):

-The simplicity of laying, trimming, and nailing without demanding skilled labors

-Needless for plaster-soil coat to make the surface of rendering even

-Compatible with the environment due to reducing both fossil fuels use and respective greenhouse gas (e.g.: CO_2) emissions, as well as low generation of waste materials during construction, and

-Reduction in labors and transportation costs due to its light weight.

Today, the relationship between human societies and their natural environment has been strongly affected by urbanization and urban development (Roshan *et al*., 2010). For instance, CO_2 emission has an upward trend (Solgi *et al*., 2009). Also, IPCC estimates CO_2 damage cost value as \$80/t (value of CO2 abatement implied by the Renewable Order Certificate ((ROC) schemes) (Shafiepour *et al*., 2005). Thus, its emission reduction has a key role for environment which can be reached through energy saving by utilizing proper housing material such as FLC block.

Some characteristics of FLC block and other common wall materials are given in Table 1. FLC block, pressed brick, and terra-cotta block sizes are 60×40×10 cm, 22×11×5.5 cm and 25×20×10 cm, respectively.

Thermal conductivity of FLC block specimen used in this research varied from 0.12 to 0.25W/mK for 600 to 1200 kg/m^3 density range, respectively. These values are specifically assumed to be 0.12W/mK and 600kg/m^3 for thin walls and 0.16W/mK and 800kg/m^3 for thicker ones. After 28 days, range of foam concrete compressive strength is between 2.5 and 5MPa depending on sand-cement ratio. Furthermore, both water absorption and drying shrinkage values are very low (5% and 0.08mm/m respectively) which prevents building façade from cracking. This sample of FLC block can also resist 25 frequent freezing and thawing cycles.

Table 1: Main properties of FLC block compared to other wall materials

Property	FLC block	Pressed brick	Terra-cotta block	3D panel
Specific gravity (kg/m^3)	300-1800	1500-1700	1000-1200	112
Weight of 15 cm wall (kg/m^2)	130	259	174	158
Speed of laying (m^2/day)	50	16	33	45
Waste during construction (%)	<3	5-7	10-12	<3
Construction cost per m^2 wall (US \$)	22.75	22.70	21.50	26.60

Heat transfer, as energy in transit due to a temperature difference, has three different processes including conduction, convection and radiation (Saimi, 2005), (Incropera and Witt, 2002). Heat conduction through external walls of a house is the most important method of heat transfer in residential buildings (Fasihi, 2006).

Since energy saving in buildings leads to CO_2 emission reduction, is highly important, because CO_2 has global negative health and environmental impact as a greenhouse gas (Ghanavati, 2010). The main source of CO_2 in urban areas is fuel burning (Peptenatu ***et** al*., 2010). So, reduction on fuel consumption in residential areas can lead to less CO_2 emission. Hence, the research aimed to estimate the potential natural gas saving as well as calculating approximate CO_2 emission reduction through utilizing FCL blocks instead of commonly used material in housing such as pressed brick, terra-cotta block, and 3D panel, while comparing the results of different areas of building as well as different heights.

MATERIALS AND METHODS

For calculating gas consumption rate in residential building systems, Behsazan software is used for analysis of energy utilization at Iranian climatic conditions (MOE, 2004). This software has been developed at Energy and Load Management Department of Niroo Research Institute (NRI) affiliated to Iranian Ministry of Energy and it has the following features (MOE, 2004):

-Implementation of building architectural elements

-Modeling of residential buildings

-Weather database for 140 cities of Iran and possibility of revising or adding any other weather data

-Load and Energy calculation based on Iranian National standard or American Society of

Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) standard
-Calculation and optimization of building Heating, Ventilating and Air Conditioning (HVAC) systems
-Lighting systems Calculation
-Calculation of domestic hot water and cold water consumption
-Database for technical specification and prices of building materials and systems
-Application of thermal insulation and HVAC systems design criteria based on Iranian National Building Code (Chapter 19) (OCDINC, 2002)
-Optimization of energy consumption in residential building based on Annual Life Cycle Cost (ALCC) economic analysis
-Assessment of energy conservation opportunities (ECOs), and
-Presentation of all calculations and output reports.

Behsazan software has some assumptions in modeling of residential building as follows:
-The simulated residential building through Behsazan software is located in downtown of Tehran and has a distance of about 10m from surrounding buildings. Thus, all external walls are considered face walls (Fig. 1),
-The climatic data is based on Tehran Mehrabad synoptic station measurements(IMET, 2009)
-An average of 4 people live in each construction unit
-The central heating system is radiator with gas boiler. Also, the cooling and water heater systems are water cooler and gas water heater, respectively
-The lighting system includes 90% incandescent lamps and 10% fluorescent lamps,
-The calculation of gas consumption is based on Iranian National standard
-Materials used in all parts of the building such as floors, doors and windows, except walls, are staying the same against varying the building height, and
-Different wall materials are FLC block, pressed brick, terra-cotta block, and 3D panel, individually.
The most important parameter in simulation of a typical residential building is thermal

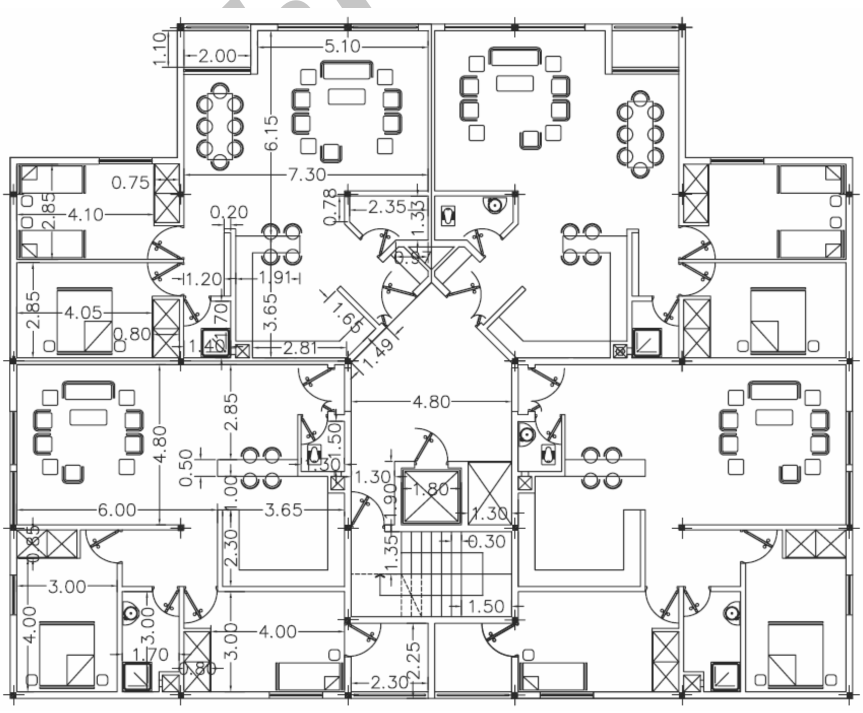

Fig.1: The simulated residential building plan

transmittance of walls, known as U, which is defined as the rate of heat transfer through one square meter of a wall if the difference in temperature between two sides of the wall is equal to 1°C and it is expressed in Watt per square meter per Kelvin (W/m^{2}K) (OCDINC, 2002). The less thermal transmittance of building elements, the less energy consumption of a structure. This parameter should be calculated manually for each wall through equations (1) and (2) and then it is entered into Behsazan software.

Where:

$$R = \sum \frac{X_i}{\lambda_i} \quad (1)$$

R: thermal resistance (m^{2}K/W),
X_i: thickness of material (m),
λ_i: thermal conductivity of a material (W/mK), and
i: type of material

$$U = \frac{1}{R} \quad (2)$$

Where:
U: thermal transmittance of a wall (W/m^{2}K),

Considering equations (1) and (2), R and U for FLC block, pressed brick, terra-cotta block and 3D panel walls are found as follows:
The values 0.06 and 0.11 are thermal resistances of external and internal air filters covering the walls (m^{2}K/W), respectively (OCDINC, 2002). Details and thermal transmittance of these walls are indicated in Table 2.
To calculate the reduction in CO2 emission, regression method had been applied. The values of *x axis* (number of floors) and *y axis* (gas consumption) are already known from simulations and are therefore fixed, so it is not quite right to consider them in this development as variables. The true variables will be the coefficients that are adjusted to give the best fit (Decoursey, 2003).

RESULTS

Firstly, as shown in Table 2, thermal transmittance values of FLC block, pressed brick, terra-cotta block, and 3D panel walls are 0.682, 2.686, 2.135 and 0.757 W/m^{2}K, respectively. Therefore, among these 4 types of face walls, FLC block and pressed brick walls lead to the most and least energy saving in building, respectively.
Completing implementation of building architectural elements and loading the relevant information such as U-value, climate data, water heater, heating and cooling systems as inputs into Behsazan software, heating energy as well as gas consumption rate are calculated based on selected standard, certain area and height of the buildings. The results of software output analysis concerning different heights or different areas are presented as follows. Additionally, the effect of gas saving on reducing carbon dioxide emissions through utilizing FLC block walls in comparison with other three kinds of wall materials is calculated. It is notable that Behsazan software has a comprehensive database of what it needs to be fed into. It contains climate data of 140 cities in Iran including Tehran, water heater, heating and cooling systems. This advantage as well as advantages (presented in pervious section) have caused to select Behsazan rather than other softwares such as ASEAM, BLAST, CHVAC,Comcheck,DOE-2, EnergyPlus, ENERPASS, HAP, TRACE 700, and VisualDOE.

Gas consumption in the building with constant area and variable heights

The most remarkable gas consumers in the simulated residential building are prioritized by i) heating system (radiator with gas boiler), ii) cooking appliances, and iii) gas water heater. As stated earlier, required gas to cook and provide hot water is assumed to be equal for all floors and wall materials. Thus, the difference in gas consumption is directly related to application of different wall materials.
In order to better understanding of gas saving rate through utilizing FLC block walls, gas consumption rate of FLC block walls in Table 3 is considered to be as one benchmark unit

Table 2: Details and thermal transmittance of FLC block, pressed brick, terra-cotta and 3D panel face walls

Material	Thickness (cm)	Thermal conductivity (w/mK)
FLC block wall		
Granite stone	2	2.2
Sand-cement mortar	2	1.15
FLC block	20	0.16
Plaster mortar	1	0.50
	Total thickness = 25 cm	Thermal transmittance (U) =0.682 W/m^2k
Pressed brick wall		
Granite stone	2	2.2
Sand-cement mortar	2.5	1.15
Pressed brick	10	1
Plaster-soil mortar	1.5	0.35
Plaster mortar	1	0.35
	Total thickness = 17 cm	Thermal transmittance (U) =2.686 W/m^2k
Terra-cotta block wall		
Granite stone	2	2.2
Sand-cement mortar	2.5	1.15
Pressed brick	10	0.51
Plaster-soil mortar	1.5	0.35
Plaster mortar	1	0.35
	Total thickness = 17 cm	Thermal transmittance (U) =2.135 W/m^2k
3D panel wall		
Granite stone	2	2.2
Shotcrete concrete	4	1.15
Polystyrene	4	0.038
Shotcrete concrete	4	1.15
Plaster mortar	1	0.5
	Total thickness=15 cm	Thermal transmittance (U) =0.757 W/m^2k

and other values are calculated proportionally. Accordingly, saving gas consumption through utilizing FLC block walls is obtained in contrast with other wall materials for buildings with different heights (Fig. 2).

Table 3 and Fig. 2 show that the application of FLC block in walls and partitions of different floors can significantly decrease the annual gas consumption of the building. This decrease is more perceptible compared to pressed brick and terra-cotta block walls due to less thermal transmittance of FLC block walls. The annual gas saving range for FLC block walls in comparison with pressed brick, terra-cotta block and 3D panel walls is from 25.7% to 30.6%, 18.5% to 23.3% and 4.6% in different numbers of floors, respectively. In fact, low thermal conductivity of FLC block is due to the porous structure of FLC

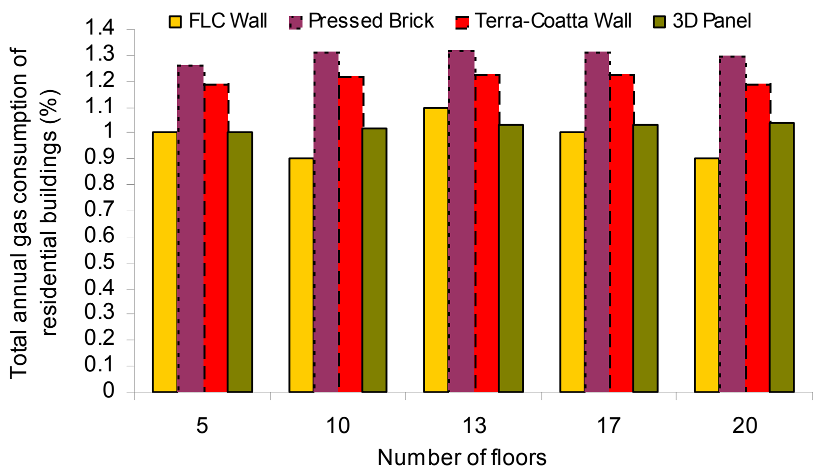

Fig.2: Comparison of FLC block building annual gas consumption versus other common wall materials

Table 3: Annual gas consumption concerning different wall materials for buildings with various heights

Numbers of floors	Gas consumption rate (thousand cubic meters per year)			
	FLC block	Pressed brick	Terra-cotta block	3D panel
5	61.158	76.91	72.51	61.158
10	119.96	156.543	147.875	125.486
13	154.796	202.224	190.934	161.982
17	204.244	266.132	251.486	213.644
20	242.08	314.813	297.605	253.14

Table 4: Reduction of CO_2 emission per unit area of the building utilizing FLC block walls for various heights

Number of floors	FLC block compared to pressed brick (kg CO_2/m^2)	FLC block compared to terra-cotta block (kg CO_2/m^2)	FLC block compared to 3D-panel (kg CO_2/m^2)
5	20.81	15.00	0.01
10	24.00	18.20	3.34
13	24.31	18.44	3.52
17	24.01	18.04	2.87
20	24.25	17.99	2.51

block where air bubbles within the block are not connected to each other. In other words, the air voids within FLC block, contrary to pressed brick or terra-cotta block block, are not interconnected to form a channel and easily conduct heat, but they act as a barrier to impede heat conduction within the walls. Consequently, dissipation of heat energy from inside to outside of a house will be dramatically reduced. Actually, a thick polystyrene layer in 3D panel walls, which is a good thermal insulation, performs almost the same as FLC block walls in gas consumption reduction.

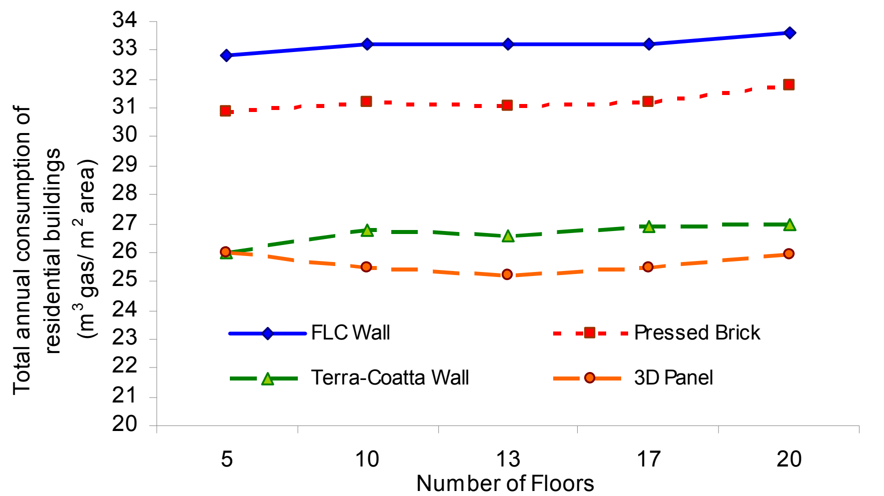

Fig.3: Gas consumption of the building versus height and walls materials variations

Carbon dioxide emission

The most destructive effect of natural gas consumption is emission of carbon dioxide (CO_2) which is a critical greenhouse gas. It has been calculated that 1 m^3 of gas consumption in residential buildings in Iran leads to 3.1 kg carbon dioxide emission (MOE, 2007). Table 4 indicates the figures of reduced carbon dioxide released into the atmosphere as a result of utilizing FLC block walls in contrast to the other walls. These rates are calculated on the basis of obtained values from the equations in Fig. 3 utilizing regression method.

DISCUSSION

This research showed that utilizing FCL blocks in housing has significant reduction in CO_2 emission. Since there has not been any similar idea to estimate gas consumption and CO2 emission reduction due to applying FCL blocks instead of commonly used jousting material, it is not possible to compare the results of this study with others.

Results show that the amount of gas consumption ascends along with raising the height of the building that leads to enhancement of the area of building envelope and consequently higher heat conduction through walls. Also, the capacity of central heating system increases and it consumes more gas in order to heat more volume of water for more and higher floors. In the meantime, length of installation pipes and their heat convection and consequently heat dissipation through them increase.

In order to obtain gas consumption rate for 1 unit (one square meter) of the building area in various heights, the values presented in Table 3 are divided by “Numbers of floors × 470 m^2” which is shown in Fig. in which the most fitted curve passing through points along with its equation is illustrated for each material.

As shown in Fig. 3, the amount of annual gas consumption in five-story house (common height for residential buildings of Tehran) is nearly 26 m^3 gas/m^2 (area) for FLC block and 3D panel walls, and 30.85 and 32.73m^3/m^2 for terra-cotta block and pressed brick walls, respectively. Also, annual gas consumption of each wall material only varies about 1 m^3/m^2 for buildings with various heights. Indeed, the annual gas consumption of unit area of the buildings is not significantly affected by their heights.

According to FLC block curve in Fig. 3, the least annual gas consumption (25.33 m^3/m^2) occurs in thirteen-story building. In addition, by substituting different values representing number of floors into the equations illustrated in Fig. 3, the most annual gas saving rates through utilizing FLC block walls comparing with pressed brick, terra-cotta block, and 3D panel walls stands at 7.84, 5.95, and 1.134 m^3/m^2, respectively.

Gas consumption reduction in residential buildings through FLC block walls results in less carbon dioxide emission specially compared to pressed brick and terra-cotta block walls with figure of 24 and 18 kg CO_2/m^2 as an average, respectively.

The CO_2 emission reduction values through FLC block walls utilization (table 4) have a direct relation with gas saving rates. For instance, CO_2 emission reduction has its highest value in 13-story building, which has the most gas saving rate. In this building, the emission reduction for FLC block walls is 24.31, 18.44 and 3.52 kg CO_2/m^2 (area) compared to pressed brick, terra cotta block and 3D panel walls, respectively.

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