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Assessment and Deployment of Ground Source Heat Pump for Air Pollution Reduction in Tehran, Iran

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Abstract
The use of renewable energies, especially in metropolises has led to a reduction in environmental pollution and greater access to clean, renewable and sustainable energy. This paper evaluates the effectiveness of a national plan adopted by the Tehran city council for reducing air pollutions. This plan is designed to increase the share of renewable energies in residential buildings. This study assumes that the extended renewable share is supplied by ground source heat pump (GSHP) systems. The number of Residential Building Permits (RBPs) issued by the city government is predicted in the next five years. Then the effects of using GSHPs on the amount of consumed electricity power and Gas are estimated by considering the policies intended for using GSHPs in Tehran. Finally, the reduction amount of air pollutants is calculated by considering the obtained results from the previous step. The reduction in gas consumption is estimated to be 4,810,848 m^3. As a result of this reduction, 9429 tons of CO_2, 201 kg of SO_x, and 10 tons of NO_x are prevented from releasing into the atmosphere. The increased amount of electricity power from running GSHPs in the residential buildings is predicted to be 11,182,543 kWh. The natural gas consumption savings is nearly 50% regarding using combined cycle power plants to generate electricity. The results demonstrated that the plan leads to decrease the emission of CO_2 and SO_x, and increases in NO_x emissions when the excess electricity is supplied by the steam turbine, gas turbine, and combined cycle power plants.

Keywords: Air Pollution, Renewable energies, Heat pump, Residential buildings, Iran.

Introduction

Air pollution is one of the main challenges in metropolises. For instance, Sao Paulo, Delhi, Mexico City, Tehran, as well as various European cities have been experiencing severe air pollution in the recent years(Calderón-Garcidueñas et al., 2015). Industries, transportation, domestic heating, construction activities, and waste incineration result in augmentation of air pollution metropolises(Sari & Bayram, 2014). A number of efforts have been made for controlling the air pollution, among which employing renewable energies have been prominent

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(Jiang et al., 2013). Renewable energies have a great potential in controlling air pollutants and moving toward a cleaner environment (Keleş & Bilgen, 2012).
Geothermal power is one of the most practical kinds of renewable energies has a considerable capability to contribute to sustainable energy development, and as one of the aspects of sustainability, it can dramatically reduce air pollution (Kagel & Gawell, 2005). Among diverse techniques of using geothermal energy, GSHPs have drawn many attentions in the last decades(Yang et al., 2010). GSHPs do not require deep excavation, and the relevant digging costs of such systems are than other geothermal techniques (Rey et al., 2004). Moreover, GSHP systems consume less electricity in comparison with conventional heat pumps, and as a result, GSHP systems produce less air pollution (Kim et al., 2013).

In the recent years, several studies have been carried out in GSHP systems. The overview of GSHPs in Europe is studied by Bayer et al. (2012). Koroneos and Nanaki (2017) assessed the technical and environmental performance of a ground source heat pump system by using Life Cycle Assessment (LCA) method in Greece. The results demonstrated that by using GSHPs the emission of SO_2 and NO_X is reduced significantly. Younes Noorollahi et al. (2016) assessed the capacity of the GSHP system in the heating and cooling mode for greenhouses in Iran. They used Crank Nicolson method to calculate the rate of heat transfer between soil and water in pipes. The results demonstrated that using GSHPs for greenhouses in Iran is not economically. Majuri (2016) studied the required policies for the development of GSHPs in Finland. This study indicates that quality assurance should be considered in the qualification of GSHPs installers.

The feasibility and performance assessment of GSHP for different case studies by Transient System Simulation (TRNSYS) can be found in Liu et al. (2017) and Emmi et al. (2015). Zhai et al. (2016) assessed the performance of GSHPs for heating and cooling mode in Shanghai Jiao Tong University. The results demonstrated that designed GSHPs can supply heating and cooling demand for the building. Huang and Mauerhofer (2016) addressed assessment of GSHP in Shanghai, China. They pointed out that the amount of energy saving for studied case is around 40.2%. The investment for installing GSHPs will be payback in 4 years. The evaluation of geothermal resources in Tunisia has been presented by Naili et al. (2016). They assessed the performance of GSHPs for cooling mode. The results demonstrated that the potential of geothermal resources in Tunisia is remarkable. However, low amount of this potential has been exploited. Moreover, the application of GSHPs in Tunisia is cost-effective.

Zhang et al. (2016) analyzed the performance of GSHPs for cooling and heating mode for five locations in China. The results demonstrated that the weighted average Coefficient of Performance (COP) of the heat pumps is around 3.36 to 5.94. Moreover, the value of heat pumps Energy Efficiency Ratio (EER) is about 1.95 to 4.35. Kharseh et al. (2015) addressed the effect of global climate change on the performance of GSHPs in three cities with different climate condition (i.e., Stockholm, Sweden (cold), Istanbul, Turkey (mild), and Doha, Qatar (hot)). Two buildings were analyzed in each city. The results demonstrated that the climate condition has a significant effect on the performance and energy consumption of GSHPs. The amount of reduction in heating load varied 10% to 55% by considering climate condition. Moreover, they pointed out that the changing rate of energy consumption varied from 8.5% in the cold climate to 18.7% in the hot climate.

Y Noorollahi et al. (2013) assessed the utilization of GSHP systems in order to restrain CO_2 emissions in Tehran. They have calculated the heating and cooling load of a three-story municipal building in Tehran via CARRIER HAP 4.3 and estimated the CO_2 emissions through using a designed GSHP system with the mean Coefficient of performance (COP) of 4.4. The results demonstrated that the substitution of this geothermal system for both gas-burning heating system and the evaporative cooling system would result in a reduction of 3763.9 kg

$CO_2/m^2/y$. Additionally, they have estimated this potential reduction about 937.4 million tons CO_2/y for all of the residential buildings in Tehran in 2012.

This paper evaluates the effectiveness of a plan that has been adopted in order to reduce air pollution in Tehran via an extension of the renewable energies to residential buildings. It is assumed that the share of renewable energies in residential buildings is supplied just by GSHP systems. Subsequently, the amount of air pollution through the exploitation of GSHP systems is calculated and compared with the amount produced by conventional heating systems. The rest of this paper is organized as follows. Section 2 presents a plan of renewable energies in Tehran. The formal description of material and methods is presented in Section 3. Section 4 shows the numerical results. Section 5 describes the discussions. Finally, Section 6 is dedicated to paper conclusions.

Renewable energies plan in Tehran

Tehran city has confronted with air pollution since last decades. In Tehran, due to geographical conditions, the air pollutants can't escape from the lower air layers to the upper ones (Afshar & Saadatpour, 2009). Tehran is located between the 30° and 45° latitudes, thus, in terms of the vertical atmospheric currents, are in the descent location of the atmospheric air masses. This fact leads to the virtually stable atmosphere on top of Tehran. According to meteorological data, air stability is observed in more than 270 days of a year in this metropolis, specifically in the fall and winter days. Moreover, Tehran lacks strong winds, and the wind rose in this city reveal that the windless days have the share of 46% during a year. In addition, the speed of 15 percent of winds blowing in Tehran is less than 3 m/s, which are nearly ineffective in removing contaminants. In a metropolis like Tehran, due to the presence of a great number of huge buildings and multitudinous towers lead to a reduction in the wind in traversing the city (Mansouri, 2012).

Due to the Tehran's atmosphere is almost stable, the most efficacious method for handling the air pollution is abating the released emissions through the air. In the recent decade, some major plans have been implemented in Tehran for diminishing emissions such as the development of subway network, the constitution of Bus Rapid Transit (BRT) lines, rectification of gasoline quality, construction of new highways, replacement of old vehicles, and extension of green spaces and greenbelts. In the recent years, in order to further cut down on the emissions, the city government has exploited some renewable technologies such as installation of solar lights for supplying lighting in all of the public parks, solar water heaters for providing hot water needs in both public places and municipal buildings, PV panels for guide posts and traffic lights, and construction of a 3 MW power plant using the disposal system emissions as fuel. Despite, appropriate actions are taken to decrease air pollutants; however, it seems that further actions should be carried out.

As a result, in the city of Tehran, it has decided to extend renewable technologies to the residential buildings (Tehran-Municipality, 2014).This extension plan has been ratified by the Tehran city council and might implement during a five-year. In this plan, the policy has been made that, 1% of total RBPs issued by the city government from March 2014 to March 2019 are required to supply 10% of their total energy demand by renewable energies (Tehran-Municipality, 2014).

Material and Methods

The data from Statistical Center of Iran is used to predict the number of RBPs issued by Tehran municipality. Table 1 presents some information regarding these permits (Statistical Centre of

Iran, 2014), and also reveals the predicted values for next 5 year of the plan from 2014-2019. The results of the projected RBPs are shown in Fig. 1.

Table 1. Issued RBPs in last three years and predicted for 2014-2019.

Span	RBPs	Floor area of RBPs (m^2)	Residential units
March 2011- March 2012	25638	25,371,580	210,924
March 2012- March 2013	21365	24,244,431	192,432
March 2013- March 2014	18948	23,348,937	177,680
March 2014- March 2015	16134	22328331	162594
March 2015- March 2016	13872	21409962	149195
March 2016- March 2017	11928	20529365	136900
March 2017- March 2018	10256	19684988	125619
March 2018- March 2019	8819	18875340	115267

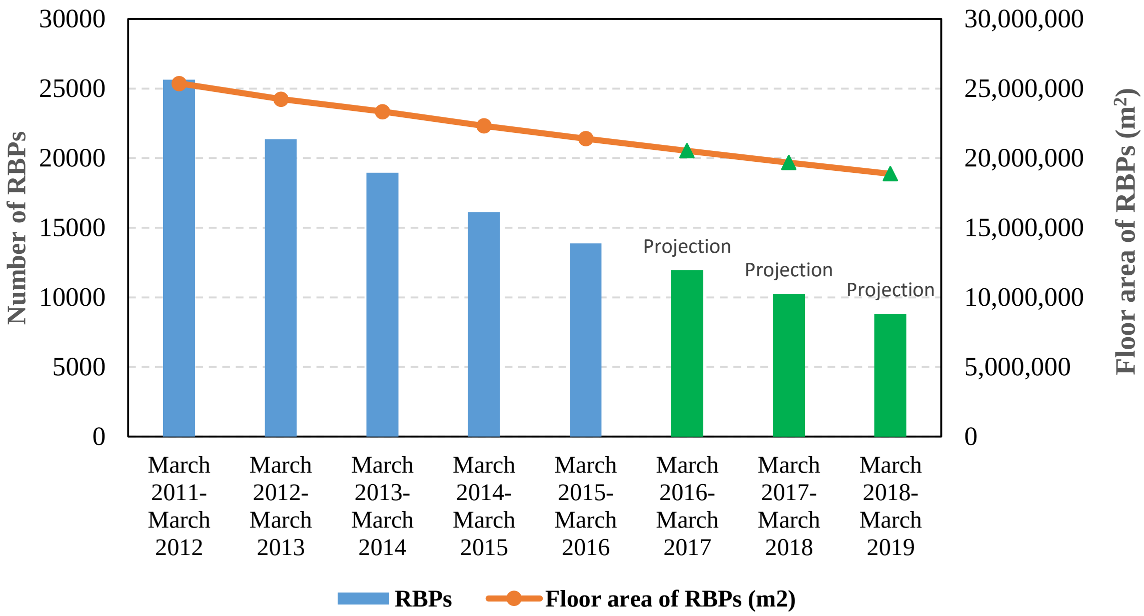

Figure 1. Issued RBPs in last three years and predicted for 2014-2019.

In this paper, we investigated the effect of using GSHPs on the reduction of air pollutants in Tehran. To calculate the reduction amount of air pollutants, in the first step, we investigate the effect of using GSHPs on the amount of consumed electricity power and Gas in the real case study in Municipality of Tehran. Then, in the second step, by considering the obtained result from the first step, we estimated the effect of using GSHPs on the amount of consumed electricity power and Gas by considering the policies intended for using GSHPs in Tehran. Finally, by considering the obtained results from the second step, the reduction amount of pollutants is calculated.

In the second step, to calculate the reduction of consumed Gas from using GSHPs in Tehran is calculated as follow:

$$V_T = \alpha \times A \times V_M \tag{1}$$

Where, V_T is the decreased amount of gas consumption in Tehran, α is 1% (The number of RBPs issued by the city government for using GSHPs from city government, A is the amount

of floor area of RBPs that considered to use GSHPs from 2014-2019 years. V_M is the decreased amount of gas consumption in Municipality of Tehran.
The increased amount of gas consuming from using GSHPs is calculated as follow:

$$E_T = \alpha \times A \times E_M \qquad (2)$$

Where, E_T is the increased amount of electric consumption in Tehran, α is 1% (The number of RBPs issued by the city government for using GSHPs from city government, A is the amount of floor area of RBPs that considered to use GSHPs from 2014-2019 years. E_M is the increased amount of electric consumption in Municipality of Tehran.

Numerical results

There have been some diffuse and sporadic reports on residential building energy consumption in Tehran in scientific sources (Ghaebi et al., 2014). In this study, we used the report of the Iranian Fuel Conservation Company (IFCO) to consider the average energy consumption in residential buildings. Based on the IFCO report, the average annual energy consumption for residential buildings, which is known as Specific Energy Consumption (SEC), is 435 kWh/m^2. 63% of this amount is provided by natural gas, whereas the rest (i.e. 37%) is provided by electricity (Eshraghi et al., 2014; Younes Noorollahi et al., 2007).

As mentioned earlier, 1% of the total RBPs issued by the city of Tehran in the planning interval is required to provide 10% of their total energy needs by renewable energies. It is assumed that this share is provided only by GSHP systems as heating equipment for buildings. In as much as the mean heating COP of GSHPs in Tehran is estimated to be 5 (Hesaraki et al., 2015), 20% of the GSHP energy input is provided by electricity, while 80% is provided by the heat from the ground beneath. Figs. 2-4, demonstrate the energy consumption breakdown before the plan, the role of the heat pump, and the energy consumption breakdown during the plan, respectively. As can be seen from Figs.2-4, 10% of building thermal energy can be provided from the ground beneath with 2.5% increasing in electricity consumption.

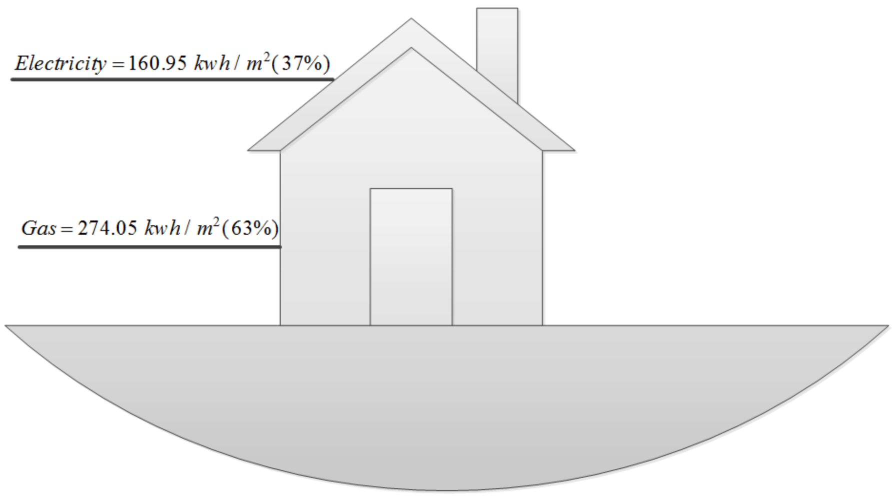

Figure 2. The energy consumption breakdown before the plan.

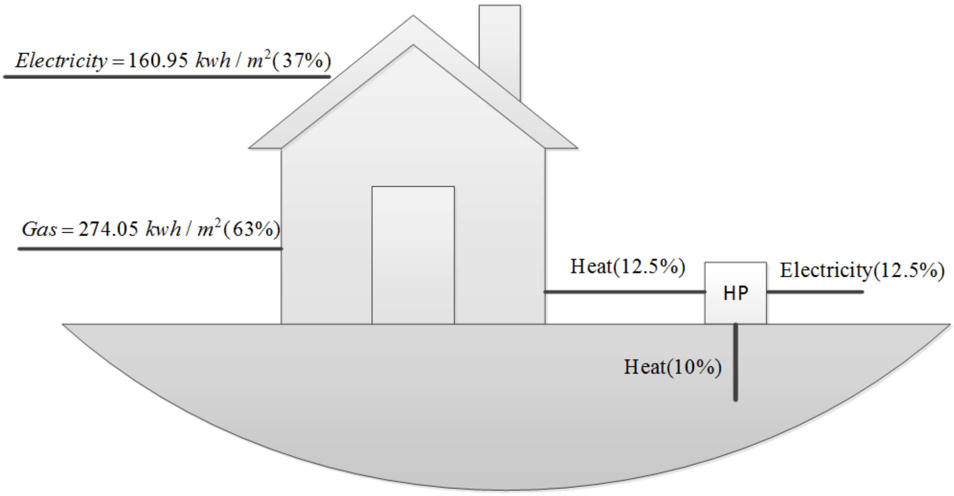

Figure 3. The role of the heat pump.

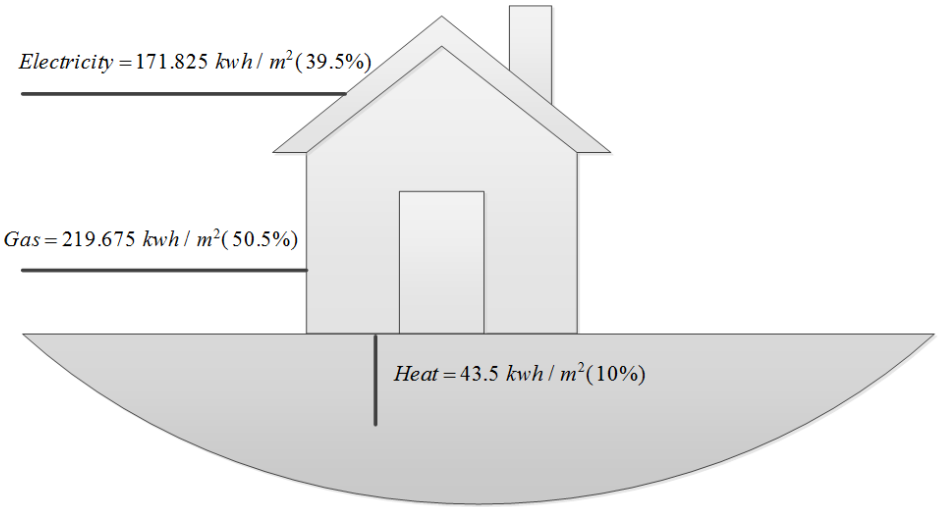

Figure 4. The energy consumption breakdown during the plan.

As can be inferred from the results of Figs. 2 and 4, the installation of the GSHP system will lead to a reduction of 54.375 kWh/m^2 in the natural gas consumption, however, at the same time, the electricity consumption will rise by 10.875 kWh/m^2. By taking into account 1% of all RBPs floor areas in the next five years and the heating value of natural gas (National-Iranian-Gas-Company, 2015), the gas consumption decrease in Tehran can be calculated as Eq. 3.

$$V_T = 0.01 \times 102827986\, m^2 \times 54.375\, \frac{kWh}{m^2} \times 860.421\, \frac{kcal}{kWh} \times \frac{1\, m^3}{10000\, kcal} = 4{,}810{,}848\, m^3 \quad (3)$$

On the other hand, the electricity consumption increase in Tehran will be calculated as Eq.4.

$$E_T = 0.01 \times 102827986\, m^2 \times 10.875\, \frac{kWh}{m^2} = 11{,}182{,}543\, kWh \quad (4)$$

By considering 15.2% loss in the electricity distribution lines (Ministry-of-Energy, 2014), we can conclude that power stations have to produce the following amount of electricity:

$$E_T^* = 1.152 \times 11182543\, kWh = 12{,}882{,}290\, kWh \quad (5)$$

The average efficiencies of power stations are 37.1%, 29.4%, and 45.6% for a steam turbine, gas turbine, and combined cycle power plants, respectively. The corresponding average efficiencies of power stations the private sector has oversight of are 34.9%, 31.5%, and 43.6%, respectively. The part of V can be used for electricity generation in the power stations. Finally, the required amount of gas, burning of which of gas to generate E_T^*, is presented in Table 2. As can be seen from Table 2, all of the obtained amounts are remarkably less than V_T. Table 3 presents the amount of gas consumption savings.

Table 2. The required amount of gas for generating E^*.

Ministry of Energy			Private sector		
Power plant	Efficiency (%)	Required gas (m^3)	Power plant	Efficiency (%)	Required gas (m^3)
Steam turbine	37.1	2987653	Steam turbine	34.9	3175986
Gas turbine	29.4	3770134	Gas turbine	31.5	3518791
Combined cycle	45.6	2430744	Combined cycle	43.6	2542246

Table 3. Gas consumption savings.

Ministry of Energy			Private sector		
Power plant	Savings in gas consumption (m^3)	Percentage of saving%	Power plant	Savings in gas consumption (m^3)	Percentage of saving%
Steam turbine	1823195	37.9	Steam turbine	1634862	34.0
Gas turbine	1040714	21.6	Gas turbine	1292057	26.9
Combined cycle	2380104	49.5	Combined cycle	2268602	47.2

The amount of gas consumption decrease (V_T), the electricity consumption increase (E_T), as well as the gas consumption savings of Tehran was calculated. It is evident that gas consumption decrease will contribute to air pollution reduction in Tehran. Table 4 demonstrated the rate of pollutant reduction per reduction of gas consumption. Therefore, the reduction amount of air pollution emission can be calculated as follows:

$$A_1 = 4810848\, m^3 \times \frac{41.84\, GJ}{1000\, m^3} \times \frac{46845\, gr\, CO_2}{1\, GJ} \times \frac{1\, ton\, CO_2}{1000000\, gr\, CO_2} = 9429\, tons\, CO_2 \qquad (6)$$

$$A_2 = 4810848\, m^3 \times \frac{41.84\, GJ}{1000\, m^3} \times \frac{1\, gr\, SO_x}{1\, GJ} \times \frac{1\, kg\, SO_x}{1000\, gr\, SO_x} = 201\, kg\, SO_x \qquad (7)$$

$$A_3 = 4810848\, m^3 \times \frac{41.84\, GJ}{1000\, m^3} \times \frac{50\, gr\, NO_x}{1\, GJ} \times \frac{1\, ton\, NO_x}{1000000\, gr\, NO_x} = 10\, tons\, NO_x \qquad (8)$$

Table 4. Pollutant emissions through gas consumption of residential buildings in Tehran (gr/GJ) (Ghiaseddin, 2007).

Gases	CO_2	SO_x	NO_x
Amount of emission	46845	1	50

On the other hand, generation of E_T^* leads to an increase in air pollution at the locality of power stations. The amount of produced air pollutant through power stations is reported in Table 5. As can be seen from Table 5, the amount of emission through gas consumption is less than Mazout. Table 6 presents the amount of emissions associated with generating E_T^* when natural gas is used in power plants. Table 7 demonstrates the estimated change in the air pollution emissions as a result of the proposed plan.

Table 5. Average pollutant emissions through electricity generation from various fuels in different power plants in Iran (gr/kWh) (Nazari et al., 2009).

Power plant	Gas			Mazut		
	CO_2	SO_x	NO_x	CO_2	SO_x	NO_x
Steam turbine	633	0	2.694	1025	15.276	2.519
Gas turbine	782	0	1.907	1048	3.842	5.792
Combined cycle	450	0	2.295	622	2.325	3.782

Table 6. Pollution emissions associated with generating E^* by gas as the input fuel in different power plants.

Power plant	CO_2 (ton)	SO_x (kg)	NO_x (ton)
Steam turbine	8154.49	0	34.70
Gas turbine	10073.95	0	24.57
Combined cycle	5797.03	0	29.56

Table 7. Estimated change in the air pollution emissions.

Power plant	CO_2 (%)	SO_x (%)	NO_x (%)
Steam turbine	-13.5	-100	+244.9
Gas turbine	+6.8	-100	+144.2
Combined cycle	-38.5	-100	+193.8

Discussions

The city of Tehran government has implemented a number of plans for rectification of the air quality in this metropolis, Tehran still suffers from an intensive air pollution, thus, further measures have to be done for relieving this problem. The city's plan, in which 1% of the total RBPs issued in the interval between March 2014 and March 2019 are required to supply 10% of their total energy demand by means of renewable energies, is one of these mitigating measures.

The number of RBPs annually issued by the city of Tehran has declined in the past three years, and further reduction is predicted by 2019. The number of RBPs will have decreased from 25638 to 8819. The corresponding floor area is predicted to decrease to 18,875,340 m^2 in 2019.

Based on the IFCO report, the SEC of residential stock is 435 kWh/m^2, with the share of 63% (274.05 kWh/m^2) for natural gas and 37% (160.95 kWh/m^2) for electricity. In this study, these shares are to be changed to 50.5% (219.675 kWh/m^2) for natural gas, 39.5% (171.825 kWh/m^2) for electricity, and 10% (43.5 kWh/m^2) for the heat from the ground beneath for 1% of the total RBPs issued by the city in the plan interval. The natural gas consumption reduction in Tehran is 4,810,848 m^3, of which partly can be utilized in gas-burning power stations for generating 12,882,290 kWh electricity in order to supply the electrical energy needs of GSHP systems in Tehran. If the mentioned amount of electricity is generated in combined cycle power plants, the natural gas consumption savings can approximately reach 50%.

Our calculations demonstrate that the city's plan will reduce natural gas consumption in Tehran, and accordingly, 9,429 tons CO_2, 201 kg SO_x, as well as 10 tons NO_x are prevented from being emitted throughout the Tehran's air. The plan leads to 13.5% reduction in CO_2, a 100% decrease in SO_x, and 244.9% increase in NO_x emissions when the excess electricity is supplied by steam turbine power plants. The corresponding results are 6.8% increase, 100% decrease, and 144.2% increase for gas turbine power plants and 38.5% decrease, 100% decrease, and 193.8% increase for combined cycle power plants respectively. Regardless of the kind of power plants, SO_x emissions will be reduced to zero. In addition, CO_2 emissions will be restricted considerably unless gas turbine power plants are utilized for electricity generation. On the other hand, NO_x emissions will rise by far on account of the extremely high temperatures in the combustion chambers of power plants which lead to the formation of a great deal of NO_x.

Conclusion

This paper has evaluated the effectiveness of a plan for reducing air pollution in Tehran. The plan aims to increase the share of renewable energies usage in the residential buildings. It was assumed that the extended renewable share was supplied with GSHP systems. Calculations indicated that the plan leads to a reduction in gas consumption of 4,810,848 m^3 in Tehran. As a result, 9429 tons CO_2, 201 kg SO_x, and 10 ton NO_x is prevented from being emitted into the Tehran's air. The increase in electricity consumption as a result of the use of GSHP systems in the residential buildings of Tehran has been predicted to be 11182543 kWh. Finally, it was ascertained that the CO_2 and SO_x emissions have been generally abated, while the NO_x emissions increased dramatically. The results reveal that this plan leads to decent results as to air pollution reduction in Tehran. The extra electricity generation for running GSHP systems are accompanied by some pollution emissions, but these emissions occur in distant places and can be eliminated in these areas before transferring to the Tehran. Furthermore, the plan is associated with great savings in natural gas consumption.

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