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ORIGINAL PAPER

Implementing green roof technology: an investigation of the effects on energy demand, fuel consumption, and pollutant emission

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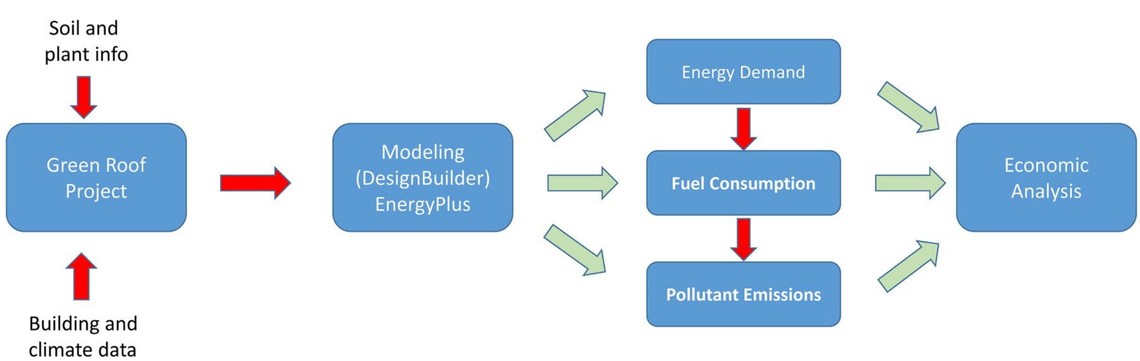
Abstract
This study investigated the effect of green roofing on energy and fuel saving and the consequent reduction in pollutant emissions in Mashhad in the hot period of the year. The DesignBuilder software package was used to model and simulate a sedum-vegetated green roof with 10-cm-thick dry soil on a 350-square meter building. The reduction in cooling load (energy saved during the hot period of the year) due to this green roof was estimated to 7.9 kWh/m^2 year. The rest of the estimations were performed based on three scenarios where the roof area available for the implementation of green roof projects in the city was assumed to be 7.8, 45, and 96 million square meters, respectively. In these scenarios, the total energy saving in the hot period of the year was estimated to 61,620, 355,500, and 758,400 MWh, respectively. It was also found that the reduced consumption of fuel in power plants because of the reduced demand for energy would result in 0.7–9 million dollars' worth of cost-saving every year. The results of the scenario analysis showed that the emission reductions due to the implementation of green roofs would be in the range of 17.5 and 299.3 (ton/year) for PM_{10}, 17.3 and 215.8 (ton/year) for CO, 154.9 and 1905.9 (ton/year) for NO_x, and 280 and 3445.9 (ton/year) for SO_2. The total reduction in the environmental damage costs of pollutant emissions in the three scenarios was estimated to 2.45, 14.21 and 30.32 million dollars per year, respectively.

Graphic abstract


Keywords Green roof · Energy · Pollutant · Economic · Environmental

Introduction

Given the vast area of roofs, roads, and other urban surfaces without vegetation cover, they can rapidly absorb the thermal radiation of sunlight and act as secondary sources of radiant thermal energy. This condition may lead to a phenomenon known as the urban heat island effect, which refers to a considerable temperature difference between an urban

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area that is mostly covered by roofs and asphalt-covered streets and its outskirts. According to a report published by the Environmental Protection Agency of the US, the temperature of an urban center can be up to 6 °C higher than that of the suburbs (EPA-US 2014). The increased temperature due to urban heat island effect leads to increased demand for energy consumption, exacerbation of environmental problems, and reduced comfort level, especially during the hot months of the year (Santamouris 2014). Among the technologies developed for energy saving in urban environments, two roof-related technologies can be considered more important than the other solutions of the same category: (i) the technology of increasing the roof albedo in order to build a "cool roof" or "reflective roof" (Zinzi 2010) and (ii) the technology of covering the roof, partially or completely, with plants in order to build a "green roof" or "living roof" (Theodosiou 2009). Although the main function of the roofs from a design point of view is to protect the interior of the building against external elements, they may also play a key role in controlling heating, cooling, ventilation, and lighting for better use of energy (Saadatian et al. 2013).

Green roofs can reduce the accumulation of carbon dioxide in the atmosphere in two ways (Whittinghill et al. 2014): (i) absorbing carbon dioxide for photosynthesis and (ii) reducing energy consumption by creating a layer of insulation and reducing urban heat island effect. The presence of green roofs can also contribute to controlling surface waters and their quality and preventing floods (Locatelli et al. 2014).

In a study by Dvorak (2007), a comparison was made between the effects of green roof and traditional roof for the city hall in Chicago and it was shown that using a green roof instead of a traditional roof would decrease the interior temperature by 12 °C. The investigations and simulations performed by Bass et al. (2003) showed that covering 50% of the roof area in Toronto with green roofs would cause a 2 °C decline in temperature. Permpituck and Namprakai (2012) studied the effect of green roofs on the annual energy needed for cooling using an empirical model. Richards (2005) investigated the spatial temperature patterns of dew and roof moisture during the summer in a residential area by the use of a simple geometrical model. Oke et al. (1991) used a model to simulate the effects of radiation, thermal characteristics, and surface moisture for different roof sizes and plant coverage. Wong et al. (2003) used the energy simulation package DOE-2 to study the effects of building a green roof above a commercial building on the annual energy saving, cooling load, and heat transfer. In a study by Li and Yeung (2014), where the environmental aspects of green roofs were studied conceptually, they emphasized the importance of using a variety of plants that would be robust against sunshine and arid weather and ensure good cooling capacity. Saize et al. (2006) compared the merits of traditional roofs and green roofs through a life cycle analysis and estimated the energy saving that can be expected from green roofs. Luo et al. (2011) studied the environmental effects and energy saving that would result from the implementation of green roof projects in central European regions by designing a software package and using GIS. Clark et al. (2008) performed a probabilistic and economic analysis to clarify the environmental benefits of green roofs as well as their economic worth. This study quantified various advantages of green roofs including easy drainage, reduced energy consumption, and reduced air pollution by an economic model that encompasses both building characteristics and urban characteristics. In a study conducted by Jaffal et al. (2012) in La Rochelle in France, a conceptual analysis was performed on the effect of green roofs on the energy performance of buildings. In this work, heat flux through green roofs was estimated and the effect of these roofs on the interior temperature and demand for heating and cooling was examined.

Ascione et al. (2013) evaluated the performance of green roofs in the Mediterranean climate of European countries from energy and environmental perspectives and identified the parameters that are effective on the technical and economic feasibility of green roofs, such as rainfall, type of vegetation, watering needs, and type of building. This study reported that the energy saving potential of green roofs is lowest when rainfall is limited and green roof needs consistent watering and argued that under these conditions, traditional roofs may be more economical than green roofs. In an experimental study carried out by Ouldboukhitine et al. (2014) on the effect of green roofs in a street canyon with temperate oceanic climate, they showed that roof temperature and air temperature in the street canyon in the summer can be lowered by up to 20 °C and 0.8 °C, respectively. Hashemi et al. (2015) studied the effect of green roofs on the quality of runoff water and energy consumption of buildings. This study concluded that green roofs reduce the energy consumption of buildings, improve environmental conditions around them, reduce building costs, and improve runoff water quality. Mullen et al. (2013) estimated the cost/benefit of installation and maintenance of an extensive green roof in Atlanta (GA) from private, public, and social perspectives. The results of their study indicated that a policy that is focused on information dissemination and technical assistance to citizens could be more cost-effective than direct subsidy payments for green roofing.

Although many studies have been conducted on the positive effects of green roofs in different climates and geographical regions, most of these studies have been focused on reducing energy consumption, fuel consumption, and economic expenses and the consequent reduction in adverse environmental impact at the international scale (Berardi et al. 2014). Research carried out in the framework of the United Nations Environment Programme (UNEP) indicates that the building sector accounts for 40% of the world's total energy consumption and 36% of greenhouse gas emissions (Besir and Cuce 2018). In Iran, however, around 47% of the total energy consumption and 40% of greenhouse gas emissions are related to the building sector (Iran's Ministry of Energy 2015). Thus, the promotion of green roofs may be a good solution for energy and environmental pollution problems of this country, especially in urban areas.

A review of the literature shows that the efforts of previous studies have been mostly focused on assessing the effect of green roofs on the heating and cooling energy of buildings. Moreover, only a few studies have engaged in simultaneous analysis of environmental effects and economic implications of green roof projects. Considering that the pollutions emitted by fossil fuel burning power plants threaten human life both directly and indirectly through the exacerbation of regional and global warming, it is necessary to shed more light on the potentially positive effects of green roofing. Given the emphasis put in the Iranian national building codes on the energy use optimization, green roofing can now be considered a viable option for reducing the energy consumed in the buildings of this country. The contribution of this study to the literature is the assessment of positive economic effects of reduced fuel consumption in power plants and reduced pollution emission alongside the positive effect of green roofing on the energy consumption in buildings. Accordingly, the main objectives of this study are: (i) evaluation of the effect of green roofing on energy consumption in buildings and consequently fuel consumption in power plants, (ii) economic and environmental analysis of the performance of green roofs in the hot period of the year in Mashhad.

Materials and methods

Study area

Mashhad is a metropolis located in the northeast of Iran and the capital of the Khorasan Razavi Province. With an area of 328 square kilometers and a population of 3,001,184, Mashhad is the second largest and the second most populous city in Iran after Tehran. This city has a temperate, variable, cold, and dry weather. The maximum temperature in the summers is around 43 °C, and the minimum temperature in the winters is around −23 °C. Figure 1 shows the average temperature and rainfall in Mashhad in different months for a 10-year period from 2004 to 2014. The average annual temperature of Mashhad is 13.5 °C, and its average rainfall is 251 mm.

The city of Mashhad consists of 12 districts, which cover an area of nearly 256.7 million square meters. According to the building regulations of Mashhad, by average, 65% of each residential land lot can be turned into a building. Thus, the maximum roof area in each land lot cannot exceed this percentage. Given the distribution of land uses in Mashhad, the total area of land available for green roofing in this city is roughly 96 million square meters.

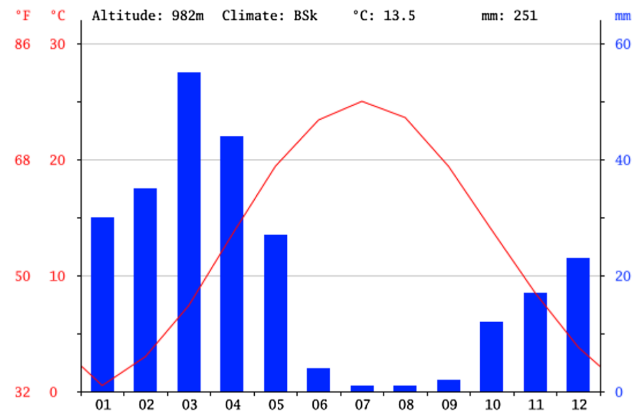

Fig. 1 Average temperature and rainfall in Mashhad in different months of the year

Energy aspect

Mashhad has four power plants, namely Toos, Mashhad, Ferdowsi, and Shariati. According to the 2014 report of the Ministry of Energy of Iran, Mashhad's power plants have a rated and actual power output of 2403 and 2113 MW and generate 10,784,506 MWh of electricity. Of this amount, 431,805 MWh is used to meet local demand and the remaining 10,352,701 MWh is fed to the national grid. To generate this amount of energy, these generators consume 163 million liters of diesel fuel, 2117 million cubic meters of natural gas, and 813 million liters of fuel oil. The thermal capacity of these fuels is 8600 kcal/L for diesel fuel, 8763 kcal/m^3 for natural gas, and 9200 kcal/L for fuel oil. Detailed information regarding the fuel type and power output of Mashhad's power plants are presented in Table 1.

Note that in some parts of Iran, including Mashhad, during the hot period of the year (from the middle of the spring to the end of the summer), the city experiences a dramatic increase in energy demand for cooling purposes, a demand that has to be met with gigantic increase in the output of power plants. In other words, the increased cooling load during this period imposes a massive pressure on power plants. It should be noted that different climates and even different regions inside the same country like Iran can have very different situations in terms of energy supply for elevated cooling loads during the hot periods and therefore very different energy consumption patterns.

Environmental aspect

The burning of fossil fuels in power plants results in generation and emission of pollutants such as PM_{10}, CO, NO_x, and SO_2 which can cause direct and indirect damages such as healthcare burden, lost income, and shortened life expectancy. Research has shown that each type of power plant can be expected to release a certain amount of each pollutant into the environment. The amount of pollution emitted by each type of fuel and plant can be quantified by a parameter called the pollutant emission factor. The pollutant emission factors of different power plants in Mashhad are provided in Table 2.

Alternative scenarios

In this study, the effect of available area on the implementation of green roofs was examined based on three scenarios. In the first scenario, it was assumed that only 50% of the roof area of government buildings is available for green roofing. In the second scenario, it was assumed that 50% of the roof area of both government and residential buildings is available. The third scenario was the completely idealistic scenario of covering 100% of the roof area of all buildings in Mashhad with green roof (see Table 3). Accordingly, the total area available for building green roofs in the first, second, and third scenario was 7.8, 45, and 96 million square meters, respectively. It should be noted that government buildings

Table 1 Fuel type and power output of Mashhad's power plants

Name of power plant	Type of plant	Type of fuel	Fuel used			Energy produced (MWh)
			Diesel fuel used (1000 L)	Natural gas used (1000 m^3)	Fuel oil used (1000 L)	
Mashhad	Steam	Natural gas	0	327,215	0	969,236
	Gas	Natural gas	0	240,000	0	629,683
		Diesel	3810	0	0	9810
Shariati	Gas	Natural gas	0	62,309	0	134,834
		Diesel	11,093	0	0	23,558
	Combined cycle	Natural gas	0	453,351	0	2,020,280
		Diesel	34,756	0	0	152,003
Ferdowsi	Combined cycle	Natural gas	0	846,526	0	2,501,063
		Diesel	113,481	0	0	329,043
Toos	Steam	Natural gas	0	247,711	0	890,472
		Fuel oil	0	0	813,079	3,068,618
Total	–	–	163,140	2,177,112	813,079	10,728,600

Table 2 Pollutant emission factors of power plants in Mashhad

Type of plant	Type of fuel	PM_{10} (g/kWh)	CO (g/kWh)	NO_x (g/kWh)	SO_2 (g/kWh)
Steam	Gas	0.08	0.35	2.7	0
	Fuel oil	0.19	0.14	2.52	15.28
Gas	Gas	0.54	0.5	1.91	0
	Diesel	0.79	0.02	5.79	3.84
Combined cycle	Gas	0.36	0.33	2.3	0
	Diesel	0.52	0.01	3.78	2.33

Table 3 Details of the assumed scenarios

Scenario	Level	Space available for green roof (10^6 m^2)	Description
0	N/A	0	The current situation
1	Medium	7.8	50% of government buildings
2	Average	45	50% of government and residential buildings
3	Maximum	96	All of the buildings in Mashhad

were considered to include government offices, educational facilities, health care centers, and hospitals, plus cultural and military buildings. All these scenarios were compared with the present situation (no green roof) to estimate how much energy in buildings and how much fuel in power plants would be conserved and what would be the effect on the cost of environmental damages.

Software

There are several software applications for simulating energy consumption in buildings. EnergyPlus is one of the most popular tools designed to model heating, cooling, lighting, ventilation and other energy, and water flows in buildings. DesignBuilder is one of the best graphical interfaces for the EnergyPlus simulation engine (Gagliano et al. 2017). In this study, two identical buildings, one with a traditional roof and the other with a green roof and both with a roof area of 350 square meters, were modeled. Then, energy transfer in these buildings was modeled. The most important characteristics of green roofs that must be incorporated into the model are soil depth, soil moisture, leaf area index, and the percentage of roof covered in green. The climate of the region is another important input parameter for modeling. It was considered that 75% of the roof area of the building would be covered with sedum plant with a leaf area index of 3 which would be planted in 100-mm-thick dry soil. The purpose of this model was to compute the amount of energy to be saved annually per square meter of green roof built.

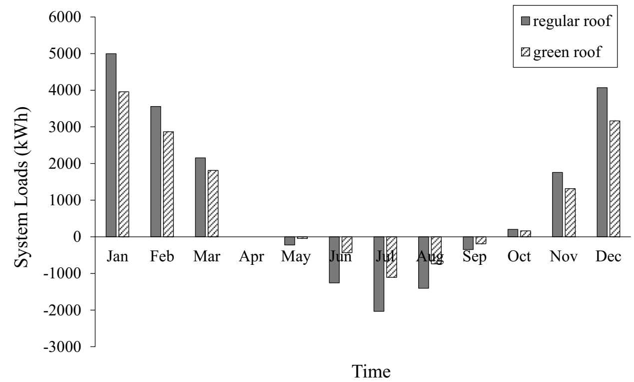

Fig. 2 Distribution of cooling and heating loads of the building models with traditional and green roofs

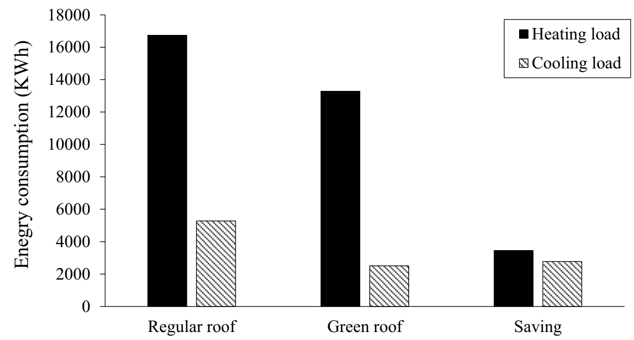

Fig. 3 Distribution of heating and cooling load

Results and discussion

Economic analysis of energy saving

The energy consumption of the buildings with and without a green roof in each month of the year was obtained from simulation. Then, the amount of heat transferred through different walls of the two buildings was studied. The cooling and heating loads of the two buildings in different months of the year are illustrated in Fig. 2.

The overall energy balance of the building shows the amount of energy lost through different walls and shell components of the building. The positive numbers represent the amount of energy absorbed from energy sources (heating load), and the negative numbers represent the amount of energy released out of the building (cooling load). As shown in Fig. 2, heating load is dominant in January, February, March, October, November, and December, which coincide with fall and winter in Iran. In contrast, to achieve thermal comfort during May, June, July, August, and September, the building has to be cooled. In Iran, these five months coincide with spring and summer. In the studied region, there is no need for heating or cooling in April. The results show considerable heat loss from the roof of the building with green roof, as compared to traditional building. In Fig. 3, a comparison is made between the models in terms of reduction in cooling and heating energy.

Although the amount of energy saved by the green roof during heating is larger, this roof has a far better performance in cooling, as it causes a much larger reduction in energy consumption in the hot months of the year. More precisely, the percentage reduction in energy consumption is 52% for cooling and 21% for heating, which means 2.5 times better performance in cooling than in heating. Permpituck and Namprakai (2012) showed that a building with a green roof with 0.2-m-thick soil has 37% lower energy consumption than a similar building with a traditional roof.

Jaffal et al. (2012) reported that with a green roof, there would be a 50% overall reduction in heating and cooling energy. Wong et al. (2003) showed that building a green roof on a five-story commercial building can result in an annual energy saving of 0.6% to 14.5%. In the study of Saize et al. (2006), it was reported that green roofs can make up to 25% reduction in the cooling demand of buildings in the hot months of the year. The results of the present study indicate that each square meter of green roof can result in an average annual energy saving of 6226 kWh, of which 2772 kWh would be related to cooling and 3454 kWh to heating.

Therefore, given the useful area of the building, the amount of energy saved annually per square meter of green roof is 17.7 kWh (7.9 kWh for cooling and 9.8 kWh for heating). Since this study was only interested in the effect of green roofs on energy consumption in the hot months of the year, only the figures related to cooling energy consumption were considered. Table 4 shows the energy demand in each scenario based on the energy saving potential considered for green roofs in comparison with the present situation (Scenario 0: no green roof).

In Table 5, the obtained results are compared with the results of studies performed on the effect of green roofs on energy demand in other countries. It should be noted that these studies have evaluated the effect of green roofs on buildings located in different climates. Moreover, these studies have considered different values for factors such as leaf area index, soil thickness, and soil moisture.

In 2004, the gross power output of Mashhad's power plants was about 10,728,600 MWh. Considering a thermal capacity of 8600 kcal/L for diesel fuel, 8763 kcal/m^3 for natural gas, and 9200 kcal/L for fuel oil, the share of these fuels in the said gross power output is 4.8%, 66.6%, and 28.6%, respectively. Table 6 presents the amount of fuel to be saved in each power plant according to the above figures. The results show that the implementation of green roof projects defined in scenarios 1, 2, and 3 would reduce the fuel consumption of these power plants by an average of 0.61%, 2.77%, and 7.61%, respectively.

According to a detailed report published by the Ministry of Energy of Iran, the 2014 price of diesel, natural gas, and fuel oil in this country has been 0.11 \$/L, 0.026 \$/m^3, and 0.062 \$/L, respectively. The reductions to be

Table 4 Energy demand in each scenario based on the energy saving potential considered for green roof

Scenario	Space available for green roof (10^6 m^2)	Energy saving (kWh/m^2(	Energy saving (MWh)	Energy required for Mashhad (MWh)
0	0	0	0	10,728,600
1	7.8	7.9	61,620	10,666,980
2	45	7.9	355,500	10,373,100
3	96	7.9	758,400	9,970,200

Table 5 Comparison of results regarding the effect of green roofs on energy demand

Study	Country studied	Climate	Tool used in the study	Energy saved (KWh/m^2 year)	Annual reduction in energy demand (%)
Santamouris et al. [37]	Greece (Athens)	Mediterranean Hot	TRNSYS Energy Plus	12.8	32
Jaffal et al. [23]	Sweden (Stockholm)	Cold	TRNSYS Energy Plus	10.7	8
Jaffal et al. [23]	France (La Rochelle)	Oceanic Moderate	TRNSYS Energy Plus	2.3	66
Wong et al. [18]	Singapore (Singapore)	Hot and Moist	Energy-DOE 2	18	16
Permpituck and Namprakai [15]	Thailand (Bangkok)	Semi hot and moist	VISUAL-DOE 4	40	31
This study	Iran (Mashhad)	Cool and dry	Energy Plus Design Builder	17.7	28

Table 6 Fuel saving in different power plants of Mashhad

Name of power plant	Amount of fuel reduction								
	Scenario 1			Scenario 2			Scenario 3		
	Diesel fuel (10^3 L)	Natural gas (10^3 m^3)	Fuel oil (10^3 L)	Diesel fuel (10^3 L)	Natural gas (10^3 m^3)	Fuel oil (10^3 L)	Diesel fuel (10^3 L)	Natural gas (10^3 m^3)	Fuel oil (10^3 L)
Mashhad	22	3299	0	128	19,033	0	273	40,603	0
Shariati	267	2999	0	1538	17,303	0	3282	36,913	0
Ferdowsi	660	4924	0	38.8	28,405	0	8123	60,598	0
Toos	0	1441	4729	0	8312	27,283	0	17,732	58,204

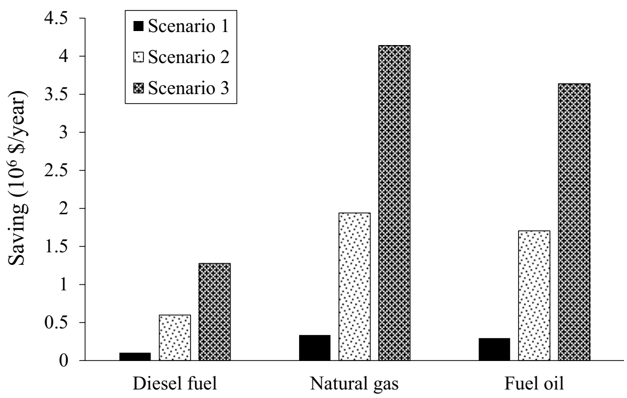

Fig. 4 Fuel cost reduction in different scenarios

made in the cost of different fuels in different scenarios are displayed in Fig. 4.

These results show that the greatest fuel cost reduction is in the cost of natural gas, which is 3.24 times the reduction in the cost of diesel and 1.14 times the reduction in the cost of fuel oil. The reduced fuel consumption (in power plants) because of the implementation of green roofs as defined in the scenarios is estimated to save 0.1–1.3 million dollars in the cost of diesel fuel, 0.3–4.1 million dollars in the cost of natural gas, and 0.3–3.6 million dollars in the cost of fuel oil annually. The study shows that the total annual cost saving to be made because of reduced fuel consumption in power plants in scenarios 1, 2, and 3 would be approximately 0.7, 4.2, and 9 million dollars, respectively. It should be noted that this study only considered the cost reduction that results from burning less fuel in power plants and ignored other possible aspects of cost saving such as labor cost and power generation/transmission cost. Also note that, the costs are only related to cooling in the hot months of the year, that is, from May to September.

According to Li and Yeung (2014), the expected annual reduction in the energy load of different buildings with different green roofs and in different climates can vary in the range of 1–40 percent. The results of the present study indicate that the average reduction in energy consumption in Mashhad after the implementation of green roof projects will be 52% in the cooling load (hot months), 21% in the heating load (cold months), and, overall, 28% in both loads (the whole year).

Economic analysis of environmental damage cost reduction

The results presented in the previous section showed that the implementation of green roof projects in Mashhad can result in a degree of energy saving in buildings. Naturally, a reduction in energy demand can translate into a reduction in the workload of power plants and therefore a reduction in the amount of pollution they emit. A summary of the results regarding the exact amount of PM_{10}, CO, NO_x, and SO_2 that will be emitted in each scenario is presented in Fig. 5. These results are based on the pollutant emission factors listed in Table 2 and the energy saving estimations obtained for Mashhad's power plants (based on the type of fuel used).

According to Clark et al. (2008), each square meter of green roofing results in an average reduction of $0.45–$1.7 in annual environmental damage costs. The study conducted by Niu et al. (2010) indicates that, on average, each square meter of green roof reduces the annual cost of environmental damages by $0.05–$0.22. In a study on the environmental damages of pollutants, Shafie-Pour and Ardestani (2007) estimated that the emission of each ton of PM_{10}, CO, NO_x, and SO_2 causes, respectively, $4300, $188, $600, and $1825 worth of environmental damage.

In the present work, the study carried out by Shafie-Pour and Ardestani on Iran's energy sector was used as a basis for determining the size of environmental damage costs imposed by the aforementioned pollutants. It should be noted that the $(GDP_y/GDP_x)^E$ correction factor had to be used to convert the environmental damage cost from the base year to the target year. Here, GDP is the gross domestic product per capita at purchasing power parity, x is the base year, y is the target year, and E is a coefficient which is usually assumed to be equal to 1. The amounts of reduction in the environmental damage costs of different pollutants in the three scenarios are reported in Table 7.

The results show that building 7.8, 45, and 96 million square meters of green roof in Mashhad will reduce the total environmental damage cost by 2.45, 14.21, and 30.32 million dollars per year, respectively. It is noteworthy that these reductions in environmental damage costs are mainly due to a reduction in PM_{10}, CO, NO_x, and SO_2 emissions. Again, it

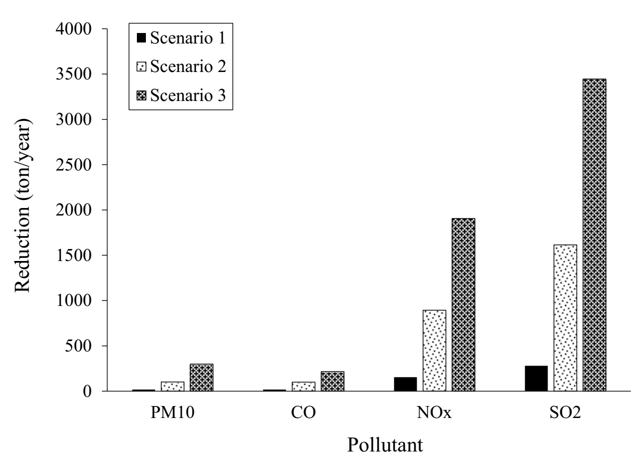

Fig. 5 Reduction in pollutant emissions after the implementation of green roof projects

Table 7 Reduction in the environmental damage costs (10^6 \$/year)

Scenario	PM10	CO	NO_x	SO2
1	0.27	0.01	0.33	1.84
2	1.57	0.07	1.93	10.64
3	3.35	0.14	4.13	22.70

should be mentioned that all of these estimations are for the hot months of the year.

Conclusion

In this study, it was shown that the implementation of green roof projects in Mashhad will result in reduced energy consumption, reduced fuel consumption in power plants, and reduced environmental damage costs in the hot months of the year. Economic and environmental evaluation of these projects for this city was performed in three scenarios: minimal use (7.8 Mm^2), moderate use (45 Mm^2), and maximal use (96 Mm^2) of available roof area for green roofing. Annual energy consumption for cooling and heating purposes in a building with a green roof was modeled with the EnergyPlus software package. The results showed that the modeled green roof makes a 52% reduction in cooling energy consumption and a 21% reduction in heating energy consumption, which means 2.5 times better performance in cooling than in heating. Each square meter of green roof was estimated to result in 7.9-kW reduction in energy consumption in the hot months of the year. The investigations showed that the amount of fuel used in the power plants of Mashhad can be reduced by 0.61, 2.77, or 7.61 percent in the first, second, and third scenario, respectively. The economic evaluations showed that there would be 0.7, 4.2, and 9 million dollars' worth of reduction in fuel consumption in the three considered scenarios.

The study also investigated the reduction in the emission of environmental pollutants, namely PM_{10}, CO, NO_x, and SO_2, following the reduction in the fuel consumption of power plants. The results indicated that the implementation of green roof projects in Mashhad as assumed in the scenarios and the consequent reduction in energy demand would result in a considerable reduction in the emission of these pollutants. Based on the pollutant emission factors of the considered power plants, the estimated reduction in the emission of these pollutants in the three scenarios will reduce the annual environmental damage cost by 2.45, 14.21, and 30.32 million dollars, respectively. The results of the present study showed that of the total cost reduction resulting from the implementation of green roofs, 23% is due to reduced fuel costs and the remaining 77% is due to reduced environmental damage costs. It should be noted that in this work, the effects of green roofing on the fuel consumed in power plants and the consequent environmental damage costs were only studied for the hot months of the year. Therefore, should the study also include the cold periods of the year, there would be a much greater reduction in energy consumption.

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