MANZAR, 14(59), 28- 37 / Summer 2022
DOI: 10.22034/MANZAR.2021.312873.2163

Persian translation of this paper entitled:
اولویت راهکارهای بهسازی نما به منظور بهره‌وری انرژی در ساختمان‌های اداری موجود شهر تهران
is also published in this issue of journal.

Original Research Article

Prioritization of Façade Retrofit Measures to Achieve Energy Efficiency in Existing Office Buildings in Tehran*

Soad Sarihi

Ph.D. Candidate in Architecture, School of Architecture and Urban Planning, Iran University of Science and Technology, Tehran.

Mohsen Faizi**

Professor in Architecture, School of Architecture and Urban Planning, Iran University of Science and Technology, Tehran, Iran.

Fatemeh Mehdizadeh Saradj

Professor in Architecture, School of Architecture and Urban Planning, Iran University of Science and Technology, Tehran, Iran.

Received: 31/10/2021 Accepted: 18/12/2021 Available online: 22/06/2022

Abstract | Addressing the problems of the inefficient existing buildings is of great importance in Tehran, where only a few buildings in the city are newly-built constructions. The existing building stock accounts for large energy consumption, and the problems of existing buildings are mostly related to the poor performance of the building envelope. The building façade, as the most significant part of the building envelope, considerably contributes to large thermal transmittance in existing buildings. As a result, studying the building envelope and especially the building façade can lead to considerable energy demand reduction in the building sector. Therefore, using façade retrofit measures can potentially reduce cooling and heating demand in existing buildings. This research tries to prioritize the façade retrofit measures based on their efficiency in reducing energy demand by adding thermal insulation, replacing windows, and adding shading to the south façade of the existing office buildings in Tehran. In other words, this research investigates the efficiency of the façade retrofit measures. It is hypothesized that using shading has more impact on reducing energy demand in south facades. This study is quantitative research drawing upon a parametrically performed simulation run by Energy Plus and Open studio in Rhino software with the help of Grasshopper plugin. The objectives were analyzed using Honeybee and Ladybug plugins. Also, a comparative study method was used to compare the energy consumption levels in retrofit scenarios and a reference model. The results show that adding shading is the most effective measure in facades with high heat transfer coefficients. In these facades, adding thermal insulation takes precedence over window replacement. Shading is still the most effective measure in facades with lower heat transfer coefficients; however, the window replacement should be prioritized to thermal insulation in retrofitting the existing façade with a higher heat transfer coefficient.

Keywords | *Facade retrofit, Energy demand reduction, Parametric modeling, Heating, Cooling.*

Introduction| The environmental problems and global warming in recent decades have underlined the significance of issues related to energy consumption. Much research has focused on designing and constructing nearly zero-energy buildings in recent decades. However, the new building stock grows at only 1-10% per year, and the large ratio of existing buildings to new constructions buildings necessitates building retrofit (Capeluto & Ochoa, 2014, 375). The existing buildings consume a large amount of energy compared to other economic sectors due to various problems related to inefficient

**Corresponding author: +989121231148, mfaizi@iust.ac.ir

building envelopes, facades, and openings (Ministry of Energy, 2013, 63).

Building envelope accounts for large thermal transmittance. The building façade, as the most significant part of the building envelope, can contribute to 20% to 30% thermal transmittance (Dall'O', Galante & Pasetti, 2012,12). In Iran, around 70% of the total energy in the building sector is consumed by public and government buildings (Molaii, Pilechiha, & Shahdanfar, 2019, 118). The cooling demand is also higher in office buildings due to the heating load of electronic equipment (Shamshiri, Davazdahemami & Atayi, 2017, 128). These issues highlight the necessity of building retrofit in office buildings. Facade retrofit can reduce the cooling and heating demand and help save energy resources in office buildings. In addition, a façade retrofit can prolong the building lifespan up to 70 years (Giebeler, 2009) and reduce energy consumption from 5% to more than 70% (Aste & Del Pero, 2013, 422). Façade retrofit measures can be enacted along with other urban regulations to achieve energy efficiency (Stevanovic, 2013, 180).

Problem statement

The building facades in Tehran are often built, disregarding energy conservation issues and façade retrofit in current urban regulations. Moreover, visual improvements are more envisaged in facade retrofit regulations. Inefficient façade components, including the facade walls and the glazing areas, can cause energy-related problems due to high thermal transmittance of the walls and windows, lack of thermal insulation, infiltration problems, insufficient shadings, and deteriorated materials. Making effective changes in façade components, especially in the equator-facing façade, and using active and passive measures can substantially reduce energy consumption in buildings. Various façade retrofit measures can be adopted to achieve this goal. Some of these measures are more effective in improving heating demand, while others reduce the cooling demand. As a result, this research aims to achieve the potential energy demand reduction by retrofitting the façades of existing office buildings in Tehran. It also attempts to determine which retrofit measures should be prioritized to minimize the heating and cooling demand.

Research aims and questions

Since this study attempts to achieve the potential energy demand reduction by façade retrofit and focuses on prioritizing the façade retrofit measures in office buildings, the following questions are raised:

- How much can façade retrofit measures reduce the average energy demand in existing office buildings in Tehran?
- How should façade retrofit measures, including thermal insulation, window replacement, and shading, be prioritized to reduce heating and cooling demand in existing office buildings?

Research hypothesis

This research hypothesizes that the cooling and heating demand in existing office buildings in the climate of Tehran can be balanced by adding shading to the building façade. Adding shading should be prioritized to other façade retrofit measures. Other retrofit measures, including thermal insulation and window replacement, should be considered after shading.

Research Background

Minor to major interventions in the building façade is considered facade retrofit. Based on different literature sources, these interventions are classified into different categories. Improving façade components, facade substitution, and double-skin façade strategies are mentioned in previous studies (Rey, 2004, 367; Rysanek & Choudhary, 2013, 325; Sarihi, Mehdizadeh Saradj & Faizi, 2021, 64; Sarihi & Derakhshan, 2018, 8). The strategies that aim to improve or replace façade components are more prevalent in related studies due to less required budget and time. The retrofit measures in these studies include thermal insulation (Alonso, Oteiza, García-Navarro & Martín-Consuegra, 2016, 252; Aste & Del Pero, 2013, 409), window replacement (Carlos & Corvacho, 2010, 568; Radwan, Hanafy, Elhelw, & El-Sayed, 2016, 3065), infiltration (Wang, Ding, Geng & Zhu, 2014, 235), shading (Aste & Del Pero, 2013, 409; Wang et al., 2014, 236), window to wall ratio (WWR) (Harkouss, Fardoun, & Biwole, 2018, 592; Zhou, Zhang, Wang, Zuo, He & Rameezdeen, 2016, 3606), Low-emissivity colors and coatings (Alonso et al., 2017, 470). The façade retrofit measures and the results achieved by using a combination of measures are shown in Table 1. A limited number of studies have investigated building envelopes and energy consumption in Iran. Some of these studies include studying building envelope materials (Shafiei Dastjerdi, Sadeghi, Rafiee, 2020, 95), using Algae Façade (Haghir, Tashakori, Rezazadeh & Ahmadi, 2020, 33), and optimizing widow proportions (Molaii et al., 2019, 118) for energy efficiency. In these studies, the effect of retrofit measures on reducing energy consumption has not been investigated dependently. In other studies that have dealt with a combination of retrofit measures, no approach has been taken to prioritize the measures in climates with heating and cooling demands. However, this research takes a different approach and examines these issues using a simulation strategy and a comparative study method.

Table 1. Façade retrofit measures and energy demand reduction in the building by using a combination of measures in heating-dominated and cooling-dominated climates. Source: Authors.

	Facade retrofit parameters				Retrofit measures	Energy consumption	
	Ref.	Insulation	Window	Shading		HVAC	Energy demand reduction
Heating-dominated climate	Tianjin, China	●	●	-	Increasing WWR to 40% in south Replacing windows double-glazing windows, Expanded Poly Styrene (EPS) for insulation	HVAC and lighting system improvement	57% total energy demand reduction (47% heating, 36% cooling, 43% lighting)
	(Alonso et al., 2016) Madrid, Spain	●	-	-	Using EPS for insulation	HVAC improvement	15.4% total energy demand reduction
	(Carlos and Corvacho, 2010) Covilhã, Portugal	●	●	-	Replacing windows and balcony doors with double-glazing Using internal EPS	-	52% total energy demand reduction
	(Wang et al., 2014) Tianjin, China	●	●	●	Reducing WWR from 65% to 50% Replacing windows with double-glazing windows, shading, insulation	HVAC and lighting system improvement	65.29-71.20% total energy demand reduction
Cooling-dominated climates	(Semprini et al., 2016) Bologna, Italy	●	●	-	Replacing windows with double-glazing windows Using very thin thermal insulation	HVAC improvement	15% total energy demand reduction (32% due to HVAC improvement and window replacement)
	(Tovarovic Ivanovic-Šekularac, & Šekularac, 2017) Belgrad, Serbia	●	●	●	Replacing windows, internal shading thermal insulation in façade and the ceiling, Infiltration improvement	HVAC improvement	72% energy demand reduction (due to double-glazing windows) and 77% (due to triple-glazing windows)
	(Song et al., 2017) Guangzhou, China	●	●	●	Using 4cm and 10cm thermal insulation Replacing windows, Infiltration improvement, shading	-	0.49-16-47% cooling demand reduction (0.49-0.83% due to thermal insulation, 2.49-4.83% due to infiltration, 4.35-10.61% due to shading)
	Alexandria, Egypt	●	●	-	Reduction of WWR in east and west Replacing windows, Using batt-fiberglass thermal insulation	HVAC and lighting system improvement	41.22% total energy demand reduction (2% due to thermal insulation, 6.3% due to window replacement, 4.3-11% due to WWR, 28-34% due to HVAC improvement)

Theoretical foundation

The concept of facade retrofit encompasses minor repairs of facade components to the overall facade improvements focusing on energy, technology, performance, and aesthetics (Wilkinson, 2012, 399). Facade retrofit in energy studies refers to interventions in existing buildings aiming to minimize the energy demand and the related energy costs (Asadi, da Silva, Antunes & Dias, 2012, 371). Retrofit measures that involve the modification and replacement of façade components are shown in a comprehensive classification in Fig. 1. Using thermal insulation, multi-glazing windows, and proper shading according to the climatic context and the energy and economic requirements can improve the thermal performance of the existing buildings (Sarihi et al., 2021). In this study, a simulation method is required to compare the energy consumption in both cases (International Energy Agency (IEA), 2013, 21; Luddeni, Krarti, Pernigotto, & Gasparella, 2018, 297). Therefore, a reference model representing the office buildings of Tehran is used to evaluate the efficiency of measures in existing office buildings.

Research methodology

To investigate the potential energy demand reduction by facade retrofit, in the first step, a reference model of an existing office building was determined in four different

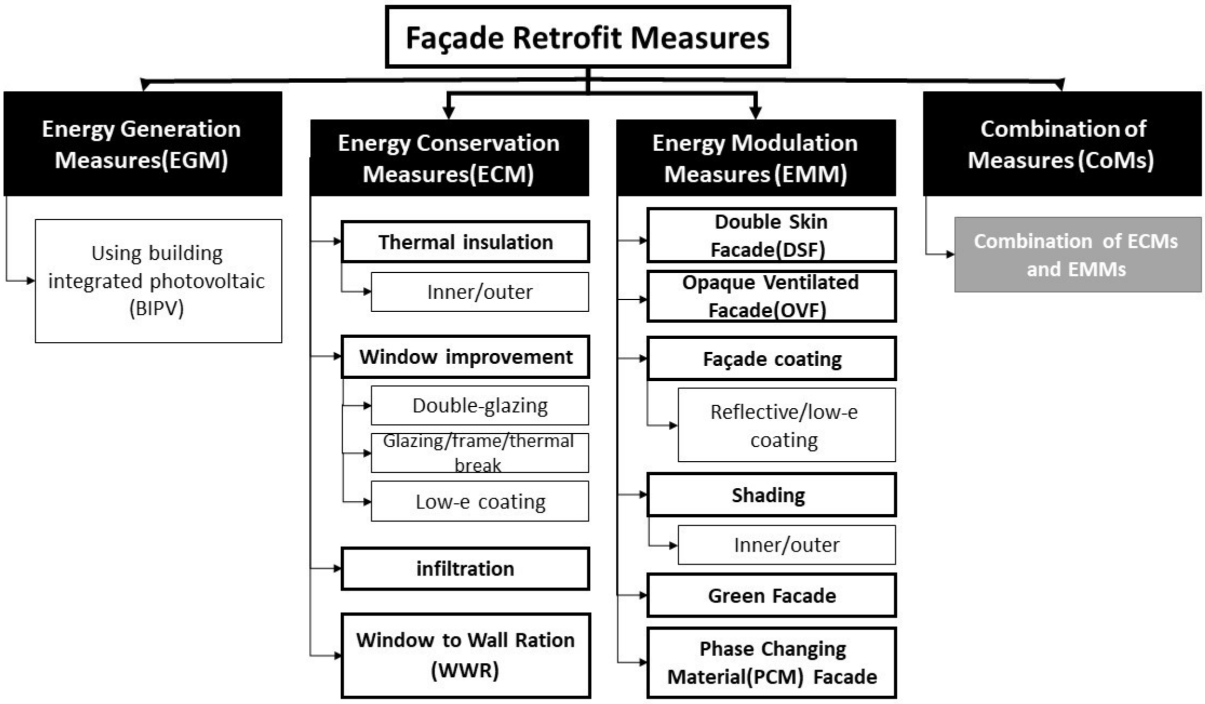


Fig. 1. Façade retrofit measures in reducing energy demand in existing buildings. Source: Sarihi et al., 2021.

types, identified as F1, F2, F3, and F4. The reference model is located in Tehran and has no shading from its surroundings. In the second step, different types of thermal insulation (A), window (B), and shading (C) were added to the reference model. In the third step, the simulation software calculates the energy demand in the existing situation and the retrofitted buildings. The simulation is performed using the Energy Plus engine (version 9.3) and Open Studio (version 3.2.0). The energy demand comparison is based on the annual cooling, heating, and lighting energy demand. Also, the software program of Grasshopper plugin in Rhino was used for parametric modeling to generate retrofit alternatives. The energy demand calculation algorithms were connected to the energy calculation engines using the Honeybee and Ladybug plugins. In the final step, the facade retrofit measures were prioritized based on the energy demand reduction in investigated alternatives. Since this study investigates the retrofit process, the framework of this study can be used for other studies and different building orientations in different climates.

Reference model

The dimensions of the reference model in this study were determined according to Reinhart's reference model, which is 6 m long, 4 m wide, and 3 m high, with an opening surface ratio of 30%, located at the height of 15 m above the ground without shading (Reinhart, Jakubiec & Ibarra, 2013). The window is 2. 4 m wide and 1.5m high, located 1 m above the floor surface. Four common types of facades in Iran were used as the reference models (Issue 55, General Technical Specifications of Construction Works, 2016). The main material in these reference models, identified as F1, F2, F3, and F4, are gray facade, clay block, Lightweight aggregate concrete (LECA) Block, and Autoclaved aerated concrete (AAC) (Rosti, Omidvar, & Monghasemi, 2020), respectively. The facade layers are described in detail in Table 2. The heating, ventilation, and cooling system (HVAC) is packaged VAV (constant temperature and variable air volume). Natural gas is used for heating, and an evaporative cooler system with electrical energy consumption is considered for cooling (Molaii et al., 2019). The average annual coefficient of performance is 3. 02 for the cooling system and 0. 8 for the heating. The ventilation system is a combination of air-conditioned air and natural ventilation (the HVAC system starts to perform where comfort conditions cannot be provided by natural ventilation). Using Tehran climate data, the weather properties were added to the reference model, and energy consumption was evaluated for a period of one year. The reference model is an office room with an occupancy rate of 0. 5 people per square meter, equipment load of 6.288 W/m, lighting load of 10. 21 W/m, cooling setpoint of 26 degree centigrade and heating setpoint of 20 degree centigrade (Shafiei Dastjerdi et al., 2020, 100), and lighting density of 300 lx during occupancy hours (8 am to 6 pm).

Retrofit measures

In this study, the combined effect of insulation (A), window (B), and shading (C) on heating and cooling demand reduction is investigated. Each of these measures was defined in several steps according to Table 3. The information about the measures and their various steps was parametrically modeled and added to the reference model. These steps were classified according to the available and economic items in the Iranian markets. Due to the limitations of building projection to the outer area, the shadings were created horizontally with a vertical distance of 30 cm from each other (Fig. 2).

Discussion

According to the findings, the retrofit interventions of this study can considerably reduce the cooling demand in existing buildings. However, they might have a counterproductive effect on reducing heating and lighting demand, primarily due to adding shadings. Still, using a proper combination of measures can lead to adequate total energy demand reduction. According to the results, the total energy demand reduction in office buildings can be reduced by 5% to 54%, similar to the results achieved by previous related studies (Sarihi et al., 2021,64). Optimum efficiency is achieved when C 2 shading is used, reducing the total energy demand by 35% to 55%. The necessity of using shading to achieve high energy efficiency is mentioned in similar studies (Capeluto & Ochoa, 2014, 382). In this study, the F 1 facade is more sensitive to retrofit measures, and the average demand reduction in F 1 is higher than in F4. In other words, retrofit measures are more effective in reducing the energy demand in facades with a relatively lower heat transfer coefficient. On average, the total energy demand is reduced by about 35% in F 1 and 22% in F4. However, selecting proper measures leads to a 54% energy demand reduction in F 1 and 46% in F4. In contrast, the energy demand only improves by 5% to 7% when inappropriate measures are taken.

• The effect of façade retrofit measures on cooling demand reduction

Changing the shading depth from 0 to 20 cm is the most effective measure in reducing the cooling demand. In this

Table 2. Existing façade layers. Source: Authors.

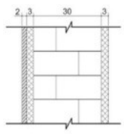
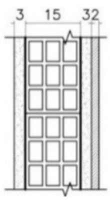
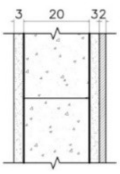
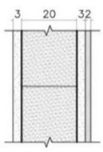
Number	Reference facade	Material figure	Layer	Material	Thickness (cm)	Heat transfer coefficient (W/ m².K)
F1	Gray Brick			Inside plaster (3 cm) Gray brick (22 cm) Sand and cement mortar (3 cm) Exterior stone or brick finish (2cm)	30	2.3
F2	Clay block			Inside plaster (3 cm) Clay block (15 cm) Sand and cement mortar (3 cm) Exterior stone or brick finish (2cm)	23	1.3
F3	Lightweight aggregate concrete Block (LECA)			Inside plaster (3 cm) LECA block (20 cm) Sand and cement mortar (3 cm) Exterior stone or brick finish (2cm)	28	1.14
F4	Autoclaved aerated concr (AAC)			Inside plaster (3 cm) AAC block (20 cm) Sand and cement mortar (3 cm) Exterior stone or brick finish (2cm)	28	0.71
Other properties				WWR: 30% - SHGC: 0.75 - VT: 0.8 Single glazing window with 4 mm glass and aluminum frame without thermal break, thermal conductivity:5.8 W / m2.K		

Table 3. Façade retrofit measures in discrete steps. Source: Authors.

ID	Parameter	Description	Thickness (m)	U-value (W/m².K)	ID
A	Insulation	Expanded Poly Styrene (EPS) Density: 40 Kg.m3	0.01	3.9	A1
			0.03	1.3	A2
			0.05	0.78	A3
			0.075	0.52	A4
			0.1	0.39	A5
B	Window	Air-filled 4-12-4 mm double-glazing window	0.2	3.2	B1
		Argon-filled 4-12-4 mm double-glazing window	0.2	2.2	B2
		Air-filled 4-12-4-121-4 mm triple-glazing window	0.36	1.1	B3
		Argon-filled 4-12-4-121-4 mm triple-glazing window	0.36	0.9	B4
C	Shading	Horizontal shading (thermally modified wood), at 0.3 m vertical distance from each other	0	-	C1
			0.2		C2
			0.4		C3
			0.6		C4

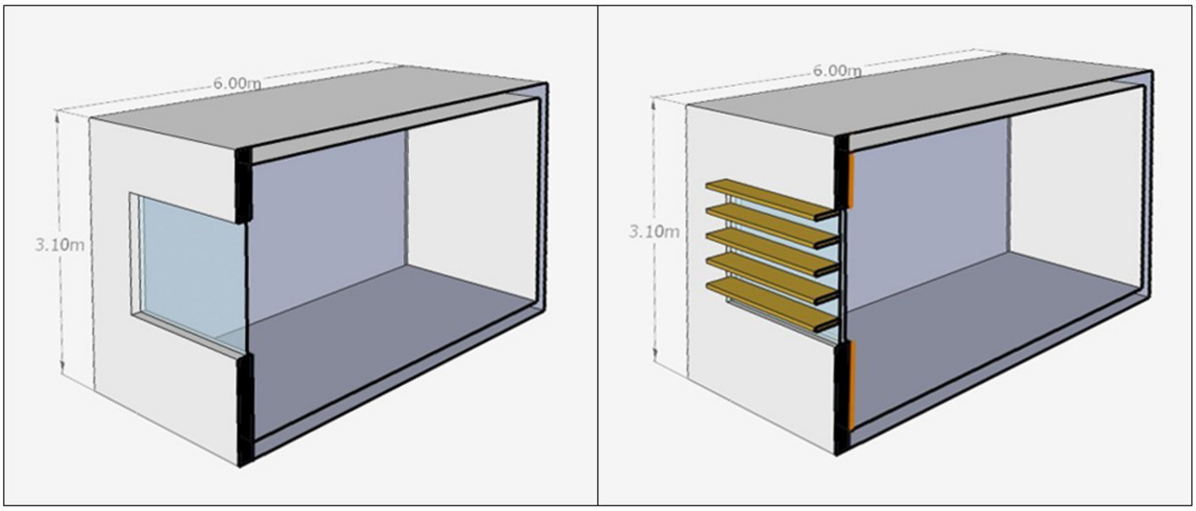


Fig. 2. Façade retrofit with thermal insulation. Right: replaced window and shading, Left: reference model. Source: Authors.

case, the average cooling demand is reduced from 20% to 46%, slightly higher than the average demand reduction by a combination of measures; that is 42% (green dashed line in Fig. 3). The positive impact of shadings with a depth of 20 cm and more in reducing the cooling demand is noticeable. Obviously, using a C 4 shading can lead to more cooling demand reduction. However, the results show that deep shading (more than 20 cm deep) is not appropriate for facade retrofit due to its counterproductive effect on total energy demand reduction. The negative effects of deep shading cannot be amended by thick thermal insulation triple-glazing windows. The cooling demand reduction by adding insulation is significant when the insulation thickness is increased from 1 to 3 cm, reducing the average cooling demand from 40% to 46%. However, no further improvement is seen when thicker insulation is used. There is an optimum value beyond which insulation has no substantial effect on reducing the energy demand (Song et al., 2017). Finally, window replacement does not affect cooling demand considerably since B 4 reduces the cooling demand by only 1% more than B1. Therefore, replacing the existing window with very energy-efficient ones may increase the improvement costs without significantly reducing the cooling demand. The data discrepancy in Fig. 4 is related to the different shading depths. Façade retrofit alternatives with no shadings are located in the lower part of the diagram, reminding the necessity of shading in south facades once again (Haghani, Mohammad kari & Fayaz, 2017, 17). Overall, parameters C, A, and B should be prioritized respectively to reduce cooling demand in existing office buildings.

• The effect of façade retrofit measures on heating demand reduction

The façade retrofit measures affect the heating demand in existing office buildings differently. For instance, shading increases the heating demand. The related studies claim that lowering the heat transmittance of the building envelope can reduce the heating demand. Hence, improving the heat transfer coefficient of the existing facades by adding insulation and replacing windows is the first step (Alonso et al., 2016, 261). Fig. 4 shows that replacing inefficient windows with multi-glazed windows reduces energy consumption by about 10% at each step. In other words, the heating demand reduction by B 4 is about three times more than that of B1. While some results show no improvement in energy demand reduction, no negative results are seen when B 3 and B 4 windows are used.

Thermal insulation is the second influencing measure in reducing heating demand. Fig. 4 shows that increasing the thermal insulation thickness from 1 to 3 cm reduces the heating demand by 13%. But the energy demand does not improve further with thicker insulation. The average heating demand reduction using a combination of measures is around 43% (purple dashed line in Fig. 4). The effect of insulation on heating demand reduction is almost parallel to the average demand consumption, indicating the low impact of this measure in the third step and beyond.

Adding shading negatively affects the heating demand reduction. The heating demand increase after the second step is noticeable. The diagrams showing the effect of insulation and window replacement in Fig. 5 show that negative results are achieved when C 4 shading is used. Using the thickest insulation layers cannot amend this negative effect in this situation. Yet, the problems of deep shadings can be considerably improved by using windows with a very low heat transfer coefficient (Drissi Lamrhari & Benhamou, 2018, 1). Therefore, parameters B, A, and C should be prioritized respectively to reduce heating demand in existing buildings.

• The effect of façade retrofit measures on lighting demand reduction

Obviously, the only measure affecting the lighting demand in this study is shading. When deep shadings are used, the lighting demand increases consequently. According to the results, the lighting demand increase by adding shading is trivial in the first step, when a 20 cm shading is used. This study does not recommend using deeper shadings since the lighting demand increases exponentially as the shading depth increases.

• The effect of façade retrofit measures on total energy demand reduction

It is necessary to see the overall impact of the retrofit measures in reducing the total energy demand in the climate of Tehran, where both heating and cooling are required in the buildings. According to the results, shading has the most significant effect on reducing the total energy demand. In this study, the total energy demand is reduced by more than 15% when a 20cm shading is added to the existing façade. However, deeper shadings increase total energy demand since the cooling and heating demands are not balanced. As a result, adding shading with a proper depth to the existing office buildings in Tehran is necessary, and it is expected to result in considerable energy demand reduction.

The performance of A and B parameters in reducing the total energy demand reduction are very similar. Fig. 5 shows that window replacement effectively reduces total energy demand at each step. Thus, window replacement should be prioritized to thermal insulation when B 3 and B 4 windows are used. Also, at least A 2 insulation (3-cm thick insulation) should be added to the existing building to achieve energy efficiency beyond the average energy demand reduction. Using thick insulation layers is recommended for F 1 and F 2 facades with relatively higher heat transfer coefficients. In façades with a lower

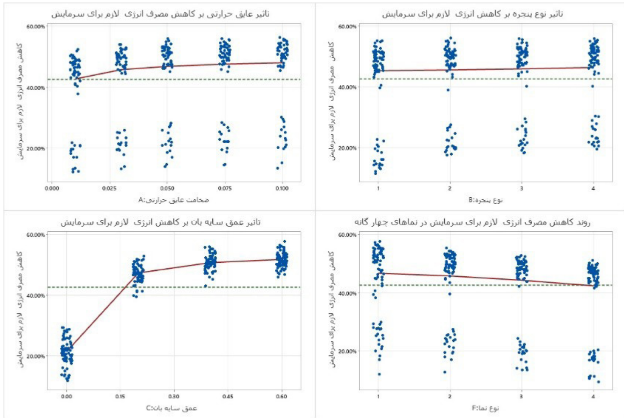


Fig. 3. The effect of façade retrofit measures on cooling demand reduction. Source: Authors.

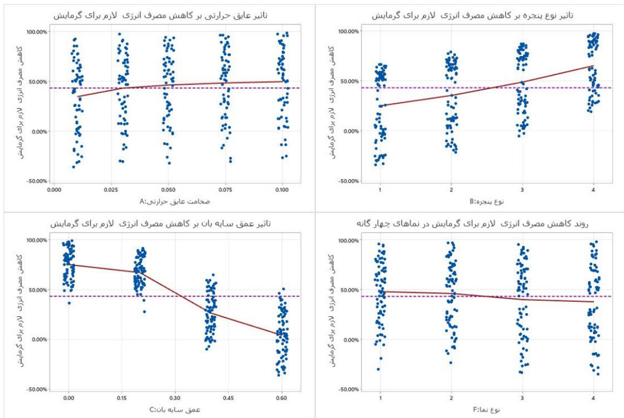


Fig. 4. The effect of façade retrofit measures on heating demand reduction. Source: Authors.

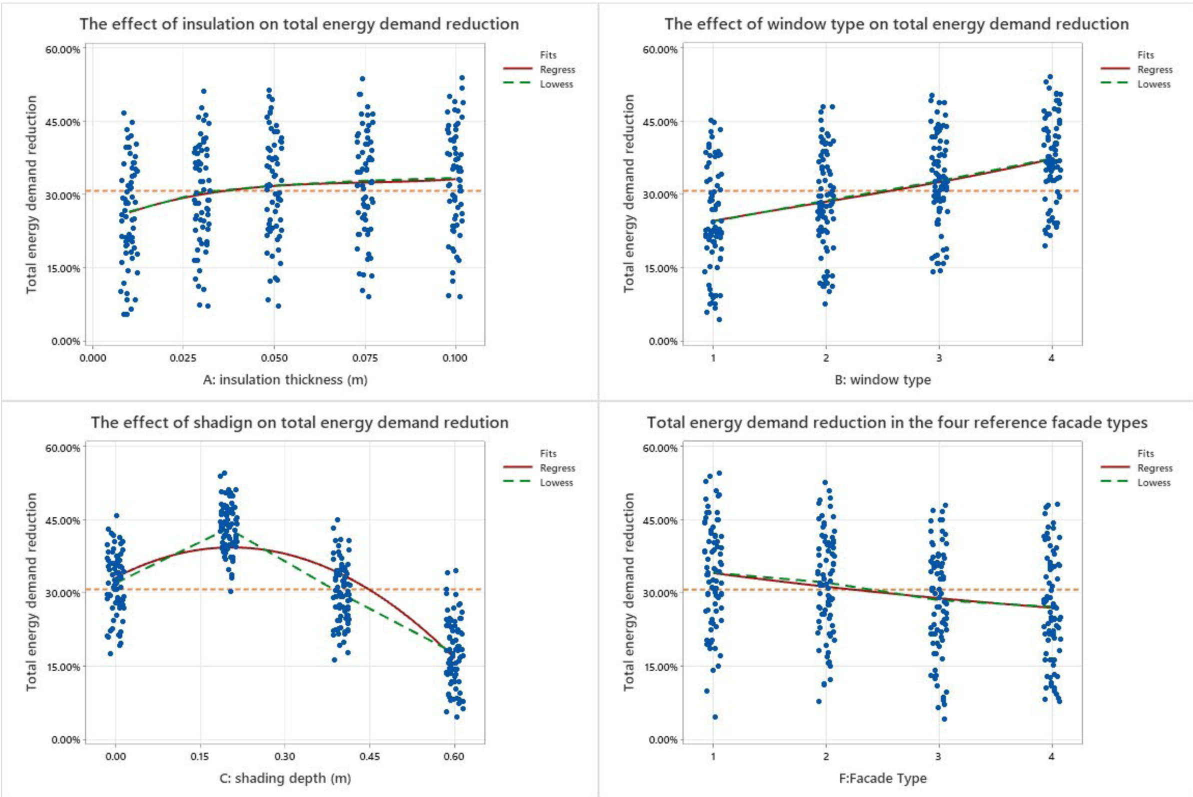


Fig. 5. The effect of façade retrofit measures on total energy demand reduction. Source: Authors.

heat transfer coefficient, thick insulation is not advisable, as it may lead to overheating. Overall, adding thermal insulation takes precedence over window replacement in buildings with high thermal transmittance with B 1 and B 2 windows. In contrast, the effect of B 3 and B 4 windows on total energy demand reduction is higher than that of thermal insulation. If the façade retrofit budget is limited, replacing the existing windows with a more energy-efficient type seems to be a better alternative for F 3 and F4.

Conclusion

Today, a large amount of energy is consumed in the building sector due to the poor performance of existing buildings and inefficient façade components. Facade retrofit can provide an opportunity to reduce energy consumption on an urban scale significantly. The results show that the average energy consumption in office buildings in Tehran is reduced by one-third after the façade retrofit. In addition, the proper selection of façade retrofit measures is likely to reduce the total energy demand by half. Therefore, it is essential to prioritize the retrofit measures based on their efficiency and select the most effective steps to minimize energy demand in existing buildings. In reducing the cooling demand, shadings, thermal insulation, and window replacement should be prioritized, respectively. In the climate of Tehran, the cooling demand cannot be reduced in the south unless proper shading is added to the existing façade. In these facades, adding insulation and replacing windows cannot replace the effect of shading. In contrast, window replacement, thermal insulation, and shading should be prioritized to reduce heating demand. Although replacing the existing windows with more energy-efficient ones can significantly reduce the energy demand in each step, there is an optimum value beyond which insulation has no substantial effect on reducing the heating demand. It is also necessary to balance the heating and cooling demand in the climate of Tehran by adding proper shading to existing office buildings, which was also mentioned in the research hypothesis. As for the second part of the research hypothesis, regarding thermal insulation and window replacement, the priorities are determined according to the façade heat transfer coefficient. In facades with higher heat transfer coefficients, thermal insulation takes precedence over window replacement. In this case, investing in thermal insulation is more profitable. In contrast, replacing the existing window with energy-efficient windows is more effective than adding thermal insulation to reduce total demand in facades with low thermal transmittance. In this case, it is recommended to invest in window replacement to achieve better results.

Endnote

* This article is derived from a Ph.D. Thesis entitled “Energy efficiency in existing buildings through façade retrofit (office buildings in Tehran)” supervised by Dr. “Fatemeh Mehdizadeh Saradj” and Dr.“Mohsen Faizi” at Iran University of Science and Technology, school of architecture and urban planning.

Reference list

• Alonso, C., Oteiza, I., García-Navarro, J. & Martín-Consuegra, F. (2016). Energy consumption to cool and heat experimental modules for the energy refurbishment of façades. Three case studies in Madrid. *Energy and Buildings*, 126, 252–262.
• Alonso, C., Martín-Consuegra, F., Oteiza, I., Asensio, E., Pérez, G., Martínez, I. & Frutos, B. (2017). Effect of façade surface finish on building energy rehabilitation. *Solar Energy*, 146, 470–483.
• Asadi, E., da Silva, M. G., Antunes, C. H. & Dias, L. (2012). A multi-objective optimization model for building retrofit strategies using TRNSYS simulations, GenOpt and MATLAB. *Building and Environment*, 56, 370–378.
• Aste, N. & Del Pero, C. (2013). Energy retrofit of commercial buildings: Case study and applied methodology. *Energy Efficiency*, 6(2), 407–423.
• Capeluto, I. G. & Ochoa, C. E. (2014). Simulation-based method to determine climatic energy strategies of an adaptable building retrofit facade system. *Energy*, 76, 375–384.
• Carlos, J. S. & Corvacho, H. (2010). Retrofit measures in old elementary school buildings towards energy efficiency. *Journal of Civil Engineering and Management*, 16(4), 567–576.
• Dall’O’, G., Galante, A. & Pasetti, G. (2012). A methodology for evaluating the potential energy savings of retrofitting residential building stocks. *Sustainable Cities and Society*, 4(1), 12–21.
• Drissi Lamrhari, E. H., & Benhamou, B. (2018). Thermal behavior and energy saving analysis of a flat with different energy efficiency measures in six climates. *Building Simulation*, 11(6), 1123–1144.
• Haghani, M., Mohammad Kari, B., Fayaz, R. (2017). The assessment of window blinds effect on conserving energy consumption of office buildings in Tehran. *Modares Mechanical Engineering*, 17(4), 17-28.
• Haghir, S., Tashakori, L., Rezazadeh, H. & Ahmadi, F. (2020). ‘Algae Façade for Reducing CO2 Emission and Mitigating Global Warming (Case Study: Tehran Enghelab Street)’. *Bagh-e Nazar*, 17(89), 33-44.
• - Harkouss, F., Fardoun, F. & Biwole, P. H. (2018). Multi-objective optimization methodology for net zero energy buildings. *Journal of Building Engineering*, 16(October 2017), 57–71.
• International Energy Agency (IEA). (2013). *Modernising Building Energy Codes*. Retrieved from https://webstore.iea.org/policy-pathway-modernising-building-energy-codes-2013.
• *Issue 55, General Technical Specifications of Construction Works*. (2016). Deputy of Technical Affairs, Office of Codification of Technical Criteria and Standards, Publications of Planning and Budget Organization.
• Luddeni, G., Krarti, M., Pernigotto, G.,& Gasparella, A. (2018). An analysis methodology for large-scale deep energy retrofits of existing building stocks: Case study of the Italian office building. *Sustainable Cities and Society*, 41, 296–311.
• Molaii, M.; Pilechiha, P. & Shadanfar, A. (2019). Optimization of Window Proportions with an Approach to Reducing Energy Consumption in Office Buildings. *Naqshejahan- Basic studies and New Technologies of Architecture and Planning*, 9(2),117-123.
• Ministry of Energy. (2013). *Iran Energy Balance Year 2012.* Deputy of Electricity and Energy Affairs. Electricity and Energy Planning Office.
• Radwan, A. F., Hanafy, A. A., Elhelw, M. & El-Sayed, A. E. H. A. (2016). Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt. *Alexandria Engineering Journal*, 55(4), 3061–3071.
• Reinhart, C. F., Jakubiec, J. A. & Ibarra, D. (2013). Definition of a Reference Office for Standardized Evaluations of Dynamic Façade and Lighting Technologies. *13th Conference of International Building Performance Simulation Association*, Chambéry, France, August 26-28, 3645–3652.
• Rey, E. (2004). Office building retrofitting strategies: Multicriteria approach of an architectural and technical issue. *Energy and Buildings*, 36(4), 367–372.
• Rosti, B., Omidvar, A. & Monghasemi, N. (2020). Optimal insulation thickness of common classic and modern exterior walls in different climate zones of Iran. *Journal of Building Engineering*, (27).
• Rysanek, A. M., & Choudhary, R. (2013). Optimum building energy retrofits under technical and economic uncertainty. *Energy and Buildings*, 57, 324–337.
• Sarihi, S. (2022). *Energy efficiency in existing buildings through façade retrofit (office buildings in Tehran).* Unpublished Ph.D. thesis. Iran University of Science and Technology, Tehran, Iran.
• Sarihi, S. & Derakhshan, Z. (2018). Advanced Integrated Facades, a New Solution to Energy Concerns. *Conference Proceedings of the International Conference in Engineering, architecture and urban management.* Conducted by Khajeh Nasir Toosi University of Technology.
• Sarihi, S., Mehdizadeh Saradj, F. & Faizi, M. (2021). A Critical Review of Façade Retrofit Measures for Minimizing Heating and Cooling Demand in Existing Buildings. *Sustainable Cities and Society*, 64, 102525.
• Semprini, G., Marinosci, C., Ferrante, A., Predari, G., Mochi, G., Garai, M. & Gulli, R. (2016). Energy management in public institutional and educational buildings: The case of the school of engineering and architecture in Bologna. *Energy and Buildings*, 126(2016), 365–374.
• Shafiei Dastjerdi, M., Sadeghi, N. & Rafiee, M. (2020). ‘Minimizing Energy Consumption by Optimizing the Exterior Skin Materials on the Scale of Urban Block A Case Study of a Deteriorated Area (Hemmat Abad, District 6 of Isfahan Province of Iran)’. *Bagh-e Nazar*, 17(91), 95-110.
• Shamshiri, S., Davazdah Emami, M. & Ataei, A. (2017). Energy Conservation using Daylight Energy Transfer through Windows : Case of Office Buildings. *Iranian Journal of Energy, 20*(2), 127-146.
• Song, X., Ye, C., Li, H., Wang, X. & Ma, W. (2017). Field study on energy economic assessment of office buildings envelope retrofitting

in southern China. *Sustainable Cities and Society*, 28, 154–161.
• Stevanovic, S. (2013). Optimization of passive solar design strategies: A review. *Renewable and Sustainable Energy Reviews*, 25, 177–196.
• Tovarovic, J. C., Ivanovic-Šekularac, J. & Šekularac, N. (2017). Renovation of existing glass facade in order to implement energy efficiency and media facade. *Energy and Buildings*, 152, 653–666.
• Wang, Z., Ding, Y., Geng, G. & Zhu, N. (2014). Analysis of energy efficiency retrofit schemes for heating, ventilating and air-conditioning systems in existing office buildings based on the modified bin method. *Energy Conversion and Management*, 77, 233–242.
• Wilkinson, S. (2012). Analysing sustainable retrofit potential in premium office buildings. *Structural Survey*, 30(5), 398–410.
• Zhou, Z., Zhang, S., Wang, C., Zuo, J., He, Q., & Rameezdeen, R. (2016). Achieving energy efficient buildings via retrofitting of existing buildings: A case study. *Journal of Cleaner Production*, 112, 3605–3615.

HOW TO CITE THIS ARTICLE
Sarihi, S., Faizi, M. & Mehdizadeh Saradj, F. (2022). Prioritization of Façade Retrofit Measures to Achieve Energy Efficiency in Existing Office Buildings in Tehran. *MANZAR*, 14(59), 28-37.

DOI: 10.22034/MANZAR.2021.312873.2163
URL: http://www.manzar-sj.com/article_141945_en.html