

PAPER • OPEN ACCESS

Cost optimal energy retrofit strategies for public administrative buildings: A Cairo case study

To cite this article: A Hamada *et al* 2021 *J. Phys.: Conf. Ser.* **2042** 012160

View the [article online](#) for updates and enhancements.

You may also like

- [Harvesting big data from residential building energy performance certificates: retrofitting and climate change mitigation insights at a regional scale](#)
João Pedro Gouveia and Pedro Palma
- [The interplay of policy and energy retrofit decision-making for real estate decarbonization](#)
Ivalin Petkov, Christof Knoeri and Volker H Hoffmann
- [The persistence of flexible coal in a deeply decarbonizing energy system](#)
Yongbin Ding, Mingquan Li, Ahmed Abdulla et al.



ECS The Electrochemical Society
Advancing solid state & electrochemical science & technology

242nd ECS Meeting

Oct 9 – 13, 2022 • Atlanta, GA, US

Early hotel & registration pricing ends September 12

Presenting more than 2,400 technical abstracts in 50 symposia

The meeting for industry & researchers in
BATTERIES
ENERGY TECHNOLOGY
SENSORS AND MORE!

 Register now!

  **ECS Plenary Lecture featuring M. Stanley Whittingham,**
Binghamton University
Nobel Laureate –
2019 Nobel Prize in Chemistry



Cost optimal energy retrofit strategies for public administrative buildings: A Cairo case study

A Hamada¹- R Raslan¹- D Mumovic¹

¹UCL, Institute for Environmental Design and Engineering, London, UK

amr.hamada.19@ucl.ac.uk

Abstract. The Egyptian government is currently constructing a new governmental quarter in the New Administrative Capital City, located east of Cairo. A planned relocation for all ministerial authorities to the New Capital City will leave a vacant governmental estate in Cairo. The study of the energy retrofit options provides a unique opportunity to reduce energy use and maximize the benefit from the anticipated investment in the re-use to be implemented within this stock. However, energy retrofit was found to be under-researched in the Egyptian context. This paper presents a pilot study that aims to identify cost optimal retrofit strategies for one of the soon to be vacated buildings, the Central Agency for Public Mobilization and Statistics (CAPMAS). Using *DesignBuilder*, an energy modelling study was implemented to estimate the existing performance of the building, assess the projected performance after a change of use (to an office building), and evaluate the cost optimality and the savings associated with the application of retrofit measures. The study found that the feasibility of implementing retrofit can be significantly offset by the discount rates in Egypt. As such, maintaining economic stability and considering non-economic incentives can be key drivers to increasing the energy retrofit uptake in Egypt.

1. Introduction

Egypt has faced pressing energy challenges in the past years. As a result of significant increases in the demand for electricity, the country became a net energy importer in 2012 [1], and in 2014, a series of countrywide electricity blackouts were implemented to manage soaring peak loads [1]. With a population increase of about 2 million people/year [2], and the increased use of mechanical cooling in buildings, the country faces even more significant future energy challenges.

In light of the anticipated relocation of the ministerial authorities to the New Capital city, more than 40 public administrative buildings in Cairo will be vacated and subjected to adaptive re-use plans [3]. While public administrative buildings use 5% of the final energy in Egypt [4], Makumbi (2017) has prioritized the retrofit of this stock, ranking it second only to upgrading the residential building stock [5]. Nevertheless, since undertaking energy efficient retrofit in Egypt has neither been mandated nor widely practiced, existing literature does not provide adequate guidance in regard to selecting optimal retrofit measures for this soon to be vacated stock of significant buildings. This study therefore aims to address this knowledge gap by exploring the cost optimality of the retrofit options proposed for a case study building from the public administrative building stock.

Following an examination of building stock data gathered from various resources [6]–[9], a building-age classification for the stock was undertaken. Based on this analysis, public administrative buildings across Cairo were found to broadly belong to three age-bands: constructed or re-used before 1925, constructed during the 1960s, and constructed after 1985. The group of buildings constructed in the



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

1960s was found to constitute the largest portion of the building stock that will be vacated. These buildings have minimal decorative exterior and interior features and, unlike buildings constructed before 1925, are neither listed nor considered ‘hard to treat’. As such, a building representative of this group, the Central Agency for Public Mobilization and Statistics (Figure 1) referred hereafter as CAPMAS, was selected as a case study for this research. The building consists of 13 floors, with an approximate area of 2600m² each, with a total building floor area of 34,000m².

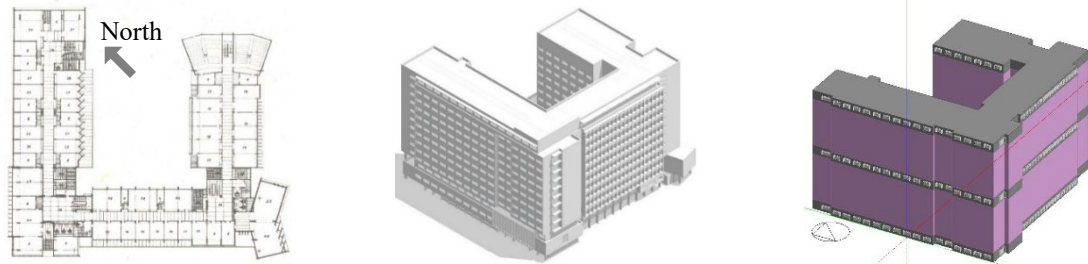


Figure 1. CAPMAS building plan drawing (left), 3D model (centre), and energy model (right)

2. Methods and assumptions

The study utilizes energy simulation to obtain cost optimal retrofit strategies for the case study building. Table 1 presents the full list of assumptions used to characterize CAPMAS and the sources from which they were derived. Based on these, a baseline energy model, shown in Figure 1, was developed using *DesignBuilder* to estimate the performance of the existing building. Baseline model assumptions were derived from walk-through audits conducted in December 2019 and September 2020.

Table 1. Baseline models assumptions for the existing building and the adjusted building after re-use.

	Existing baseline		Office building re-use scenario	
Floor height (m)	3.6			
Suspended ceiling void depth (m)	0.6			
Operation Schedules	8:30-15:30		8:30-17:30	
	Hours	Fraction	Hours	Fraction
	8:30-9:00	0.50	8:30-9:00	0.50
	9:00-15:00	1.0	9:00-17:00	1.0
	15:00-15:30	0.50	17:00-17:30	0.50
	Off on Fridays and Saturdays.		Off on Fridays, and 75% reductions on Saturdays.	
Occupancy (m ² /person)	10			
Holidays	15 days		10 days	
Clothing	Summer: 0.5 clo, winter: 1 clo			
Lighting illuminance level (lux)	250		500	
Normalized lighting power density (W/m ² .100lux)	2.056			
Equipment load (W/m ²)	15			
HVAC system	Terminal single zone DX split units (auto-sized, cooling only, COP = 3.0, continuous fan operation mode), derived from [10]			
Wall U-Value (W/m ² .K)	2.75, derived from: [11]–[15]			
Roof U-Value (W/m ² .K)	0.55 [10]			
Glazing U-Value (W/m ² .K)	6, derived from [10], [16]			
Glazing SHGC	0.82, derived from [10]			
Shading	0.5m overhangs and side-fins, at 0.2m offsets from window edges			
Window reveal (m)	0.20			
Cooling setpoint (°C)	24, derived from [10]			
Natural ventilation setpoints (°C)	22-25			
Air tightness (ach)	1.0			

Based on the assumptions summarized in table 1 for the office building use proposed, the baseline model was transformed into a projected/adjusted baseline model that estimates the energy use following the anticipated change in building use. The assumptions were derived from a workshop that was conducted with key-informants from the Egyptian context to inform the study.

A set of retrofit options (shown in table 2), with cost data gathered from suppliers in Egypt included, were applied to the office building model. The cost of the proposed measures was analyzed using the simple payback period (PB) and the net present value (NPV) over an expected lifespan of 20 years. The payback period of the retrofit options was calculated using the following equation (1),

$$Payback\ period\ (years) = \frac{Initial\ investment}{Annual\ savings} \tag{1}$$

where the initial investment represents the summation of construction costs for all the retrofit options chosen for a retrofit solution and the annual savings represent the reductions in the operational energy costs compared to the baseline case. The baseline case was calculated by multiplying the reductions in the annual operational energy use (in kWh) by the fixed tariff rate of 1.60 EGP/ kWh.

Moreover, to account for discount rates the Net Present Value (NPV) for the retrofit investment was calculated according to equation (2),

$$NPV = \sum_i \frac{Annual\ savings * fuel\ escalation\ rate}{(1 + discount\ rate)^i} - Initial\ investment \tag{2}$$

where the initial investment was based on the total construction cost for a retrofit solution, and the annual savings represent the reductions in the operational energy costs compared to the baseline case (as previously detailed), all multiplied by the fuel inflation rates derived from the Energy Price Indexes and Interest Factors in the Annual Supplement to NIST Handbook 135. *i* represents the annual iteration such that the equation sums the cash flow with *i* in the range from 1 to 20 years. The discount rate was assumed to be 8.75% based on the data derived from the Central Bank of Egypt in March 2021.

In NPV calculations, if the summation of the savings, subject to the discount rate reductions, is more than the initial investment, NPV would return a positive value which indicates that the investment is feasible as it will achieve net profit in the specified number of years. In contrast, negative NPV values denote that the chosen investment strategy (retrofit solution) will not reach the payback where the initial investment is fully retained in the indicated number of years.

Therefore, optimal retrofit scenarios should achieve minimum energy use intensity (EUI) and maximum NPV. To identify the Pareto-Front that satisfies both objectives, they should have the same goal (either to minimize or maximize both objectives). In this case the NPV formula was multiplied by -1, as shown in equation (3), such that minimizing both EUI and NPV will be the goal of the optimization, and negative NPV values in 20 years denote feasible solutions while positive values denote infeasible ones.

$$-NPV = Initial\ investment - \sum_i \frac{Annual\ savings * fuel\ escalation\ rate}{(1 + discount\ rate)^i} \tag{3}$$

In a resulting pool of 52,920 possible retrofit solutions available from the retrofit measures proposed in table 2, a Latin Hypercube Sample (LHS) of 500 solutions was selected for this pilot study to provide initial estimates of savings and the feasibility for the measures proposed. LHS was deemed to be suitable for the exploratory nature of this study as it is less computationally intensive than assessing all possible retrofit solutions (brute-force optimization) or deploying algorithmic optimization to select optimal solutions by using one of the genetic algorithms available.

Table 2. Retrofit measures performance and estimated construction cost.

External wall insulation	U-Value	Cost per external wall area (EGP/m ²)				Overall cost
		Cost		Enabling works cost		
		Material	Labour	External finish demolition	Re-finishing exterior	
Baseline (external 25cm brickwork with cement plaster)	2.752	0	0	0	100	150
3 cm EPS	0.82	49.5	50	50	100	249.5
5 cm EPS	0.558	82.5	50	50	100	282.5

8 cm EPS	0.377	132	50	50	100	332								
10 cm EPS	0.311	165	75	50	100	390								
15 cm EPS	0.215	247.5	75	50	100	472.5								
20 cm EPS	0.165	330	75	50	100	555								
Roof insulation														
Baseline (Concrete slab with 5 cm EPS included, and finishes)	0.55	0	0	35	150	185								
Using 8 cm EPS	0.386	132	50	35	150	367								
Using 10 cm EPS	0.324	165	50	35	150	400								
Using 15 cm EPS	0.23	247.5	50	35	150	482.5								
Using 20 cm EPS	0.179	330	50	35	150	565								
Windows	Performance					Cost per glazing area (EGP/m ²)								
	Glazing			Frames	Overall	Material	Replacement cost	Overall cost						
	U-Value	SHGC	LTC	U-Value	U Overall									
Single glazing														
Baseline [10], [16]	6	0.82	0.76	5.88	5.988	0	0	0						
Clear	5.7	0.51	0.32	3.4	5.47	1400	150	1550						
Blue	5.7	0.38	0.2	3.4	5.47	1500	150	1650						
Green	5.7	0.39	0.26	3.4	5.47	1500	150	1650						
Grey	5.7	0.36	0.05	3.4	5.47	1500	150	1650						
Bronze	5.7	0.43	0.18	3.4	5.47	1500	150	1650						
Double glazing														
Clear	2.8	0.44	0.3	2.5	2.77	1600	150	1750						
Blue	2.8	0.28	0.19	2.5	2.77	1800	150	1950						
Green	2.8	0.30	0.24	2.5	2.77	1800	150	1950						
Grey	2.8	0.24	0.05	2.5	2.77	1800	150	1950						
Bronze	2.8	0.34	0.16	2.5	2.77	1800	150	1950						
Double glazing, low-e														
Clear	1.8	0.35	0.27	2.5	1.87	1850	150	2000						
Blue	1.8	0.21	0.17	2.5	1.87	2000	150	2150						
Green	1.8	0.23	0.22	2.5	1.87	2000	150	2150						
Grey	1.8	0.17	0.04	2.5	1.87	2000	150	2150						
Bronze	1.8	0.25	0.15	2.5	1.87	2000	150	2150						
Double glazing low-e, 90% Argon filled														
Clear	1.5	0.35	0.27	2.5	1.6	2000	150	2150						
Blue	1.5	0.21	0.17	2.5	1.6	2150	150	2300						
Green	1.5	0.23	0.22	2.5	1.6	2150	150	2300						
Grey	1.5	0.17	0.04	2.5	1.6	2150	150	2300						
Bronze	1.5	0.25	0.15	2.5	1.6	2150	150	2300						
Window external shading						Cost per glazing area (EGP/m ²)								
Baseline (50cm deep overhangs and side fins)						0								
External louvers (6 horizontal blades, 30cm deep, inclined at 45 degrees)						500								
75cm deep Overhangs and fins (with 20cm horizontal and vertical spacing from the opening)						400								
Window internal shading						Cost per glazing area (EGP/m ²)								
Baseline (none)						0								
Internal blinds						250								
Lighting type	Illumination (lumens)	Area (m ²)	Illuminance (lux)	Normalized Lighting Power Density (W/m ² .100lux)	Lighting Power Density (W/m ²)	Cost per floor area (EGP/m ²)								
						Cost	Replacement cost	Total cost						
						16* White T8 36W fluorescent	2000 (x16)	64	500	2.056	10.28	10	10	20
						16* 18W LED tubes	2000 (x16)	64	500	1.028	5.14	25	15	40
9* 40W LED panel 60*60	3600 (x9)	64	500	1.14	5.7	50	15	65						
Daylighting control						Cost per floor area (EGP/m ²)								
Baseline (none)						0								
Stepped daylighting control sensors (2 steps)						25								
HVAC unit replacement						Cost per floor area (EGP/m ²)								
Direct expansion terminal unit (PTAC), continuous fan operation mode (replacement cost included in re-use costs)						0								
Direct expansion terminal unit (PTAC), cycling fan operation mode						250								

3. Results

Based on the model assumptions, the energy use intensity in CAPMAS was found to increase from 78 to 97 kWh/m² when the building was transformed from a public administrative into an office building. As shown in Figures 2, and 3, the study of the payback period showed that all tested retrofit solutions managed to achieve the payback in full in less than 20 years. In contrast, accounting for the discount and the fuel price escalation rates to calculate the net present value showed that only 67% of the studied retrofit solutions were found to achieve the payback within 20 years (i.e. are feasible solutions).

Reductions in the energy use intensity of up to 50% (off the adjusted baseline office building re-use scenario) could be achieved as a result of the application of the retrofit measures.

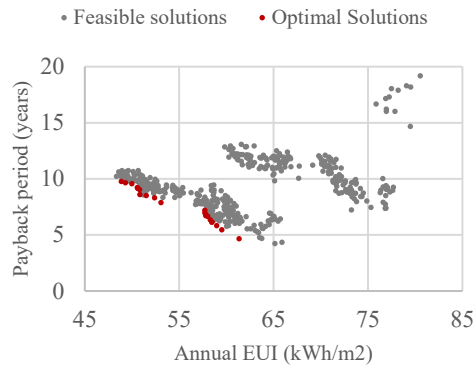


Figure 2. Optimal retrofit solutions in terms of annual energy use intensity and simple payback period

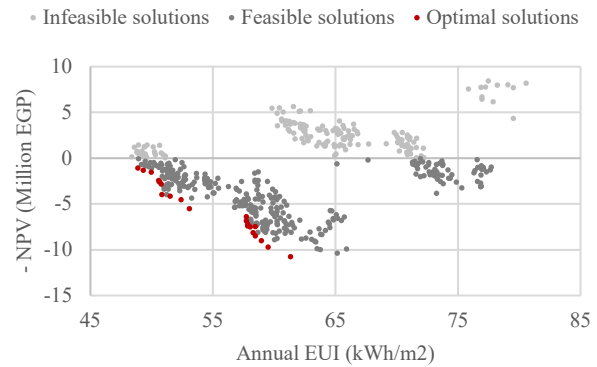


Figure 3. Optimal retrofit solutions in terms of annual energy use intensity and net present value over 20 years, at a discount rate of 8.75%

It can be noticed that the retrofit solutions in Figures 2 and 3 were clustered into 3 groups. Looking at the correlation of the different retrofit measures used to the clusters formed indicated that the change of the lighting type installed was the key driver to cluster formation as the other retrofit measures tested were found to be spread across the different clusters. The sensitivity analysis confirmed the high correlation of the EUI to the lighting template choice, followed by the external wall insulation, window blind type, and glazing type, as standard regression coefficient values of 0.60, 0.54, 0.13, and 0.12 respectively were obtained. Further investigation of those clusters will be addressed in future research.

From the 21 optimal retrofit solutions obtained from the run, table 3 presents the measures considered ‘optimal’. The number against each denotes the number of times this measure was identified by the analysis as being part of an optimal retrofit strategy, where the higher the number, the more that the measure can be considered ‘best practice’.

Table 3. The number of times the retrofit measures were found a part of the optimal retrofit solutions.

External wall insulation		Roof insulation		Glazing type		External shading		Lighting		Internal local shading		HVAC unit type	
Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure	Measure
Adding 8cm EPS	6	Roof with 10cm EPS	7	Double Glazing	8	Baseline (50cm deep overhangs and fins)	14	LED tube lights	20	Internal blinds	15	DX terminal unit (PTAC), cycling fan operation mode	11
Adding 15cm EPS	6	Roof with 8cm EPS	6	Double Glazing, low-e	6	75cm deep overhangs and fins	5	LED tubes & daylighting sensors	1	None (baseline)	6	DX terminal unit (PTAC), continuous fan operation mode	10
Adding 5cm EPS	4	Baseline roof (5cm EPS included)	3	Single Glazing	3	External louvers	2						
Adding 10cm EPS	3	Roof with 15cm EPS	3	Baseline	2								
Adding 20cm EPS	2	Roof with 20cm EPS	2	Double glazing, low-e, Argon filled	1								

Discussion and conclusion

The baseline energy consumption of CAPMAS was found to increase by almost 25% due to the change in use. This increase impacts the assessment of retrofit as it offsets the savings achieved. In real-world contexts, quantifying the actual increase in energy use or the savings achieved is challenging since the metered energy bills only show the overall combined impact of the change of use and the retrofit

measures. With the lack of data on benchmarks for different building uses, this increase in the baseline energy consumption should be carefully assessed through post-retrofit monitoring to correctly reflect the energy savings achieved.

Accounting for the discount rates when calculating the estimated savings after the retrofit uptake will have a significant impact on the optimality and the feasibility of the retrofit scenarios. Considering the inconsistent fluctuations of the discount rates in Egypt, the retrofit outcomes can be significantly diminished by discounted cash flow earned annually. In regard to the ‘best practice’ measures identified in this pilot study, the use of LED tube lights, internal blinds, UPVC double glazing and keeping the existing external shading most frequently appeared in the optimal retrofit solutions obtained.

This study provides preliminary estimates for the change of energy use after re-using the building, the retrofit savings that could be achieved, and the influence of accounting for the dimension of time when studying the feasibility of the project. Some limitations identified in this study will be addressed in the future research. For example, the baseline model will be calibrated to the actual data derived from the monthly utility bills per ASHRAE Guideline 14. Future work will also aim to consider more options for of the insulation materials and the shading systems, explain and validate in more detail the inherent assumptions of the measures, and utilize more rigorous algorithms to obtain optimized retrofit solutions.

References

- [1] International Renewable Energy Agency, *Renewable Energy Outlook: Egypt*. 2018.
- [2] CAPMAS, “Egypt in numbers- Buildings Census 2017,” 2018.
- [3] A. Morsi, “Through the tide- Adaptive reuse, creative industries, and the politics of arts-led redevelopment of Downtown Cairo - MSc. thesis in Architectural Design and History,” Politecnico Di Milano, 2020.
- [4] EEHC, “Egyptian Electricity Holding Company Annual Report,” 2018.
- [5] P. Makumbe, M. Mot, M. M. Khalil, and M. Hallouda, “Energy Efficiency and Rooftop Solar PV Opportunities in Cairo nad Alexandria :Report summary,” p. 35, 2017.
- [6] Tarek Waly Center for Heritage, “Egypt Pioneer Architects Series Dr Tawfeek Abdel-Gawad,” p. 368, 2017.
- [7] M. Hammad, *Egypt is building 1963*. مصر تبنى.
- [8] G. El Kadi, *Cairo, Centre in movement*. IRD Éditions - Institut de recherche pour le développement, 2012.
- [9] M. El-Shahed, *Cairo since 1900*. AUC Press, 2019.
- [10] A. M. Elharidi, P. G. Tuohy, M. A. Teamah, and A. A. Hanafy, “Energy and indoor environmental performance of typical Egyptian offices: Survey, baseline model and uncertainties,” *Energy Build.*, vol. 135, pp. 367–384, 2017, doi: 10.1016/j.enbuild.2016.11.011.
- [11] K. Tarabieh and A. Aboulmagd, “Thermal performance evaluation of common exterior residential wall types in Egypt,” *Buildings*, vol. 9, no. 4, 2019, doi: 10.3390/buildings9040095.
- [12] M. A. Hassan, N. M. Guirguis, A. Ibrahim, and A. A. Fahim, “Effect of Building Material and Wall Construction on the Energy Consumption,” pp. 1–7, 2011.
- [13] S. Attia and O. Wanas, “The Database of Egyptian Building Envelopes (DEBE): A database for building energy simulations,” *SimBuild 2012*, no. February 2020, 2012.
- [14] F. Bre, N. Roman, and V. D. Fachinotti, “An efficient metamodel-based method to carry out multi-objective building performance optimizations,” *Energy Build.*, vol. 206, p. 109576, 2020, doi: <https://doi.org/10.1016/j.enbuild.2019.109576>.
- [15] M. N. Mohamed M. Mahdy, “the cost of achieving thermal comfort via altering external walls specifications in egypt; from construction to operation through different climate change scenarios Mohamed M . Mahdy Marialena Nikolopoulou Centre for Architecture and Sustainable Environm,” 2015.
- [16] I. R. Hegazy, “Toward energy-efficient governmental buildings in Egypt: Investigating the impact of nano aerogel glazing on energy performance,” *Int. J. Low-Carbon Technol.*, vol. 15, no. 1, pp. 17–24, 2019, doi: 10.1093/ijlct/ctz052.