Energy Reports 15 (2026) 109066

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Distinguishing energy efficiency from substandard IEQ in Cairo's public administrative buildings: Audit-informed modelling and calibration of two cases

Amr Auf Hamada [a,b,*], Sung-Min Hong [a], Rokia Raslan [a]

[a] *Institute for Environmental Design and Engineering – The Bartlett School of Environment, Energy, and Resources, University College London, United Kingdom*
[b] *Department of Architectural Engineering – Faculty of Engineering, Cairo University, Egypt*

ABSTRACT

As Egypt relocates its government headquarters to the New Administrative Capital, nearly 50 existing public administrative buildings in Cairo await renovation and adaptive reuse. This offers a substantial opportunity for improving the performance of existing buildings, as retrofit measures could be integrated into the upcoming interventions. However, the existing literature was found to be insufficient at informing decision-makers with validated estimates of the baseline operational performance, casting major uncertainties about the retrofit outcomes that could be yielded. Following a stock analysis conducted in a previous study, where lower-than-expected metered energy use was identified, further building-level investigations of the operational performance were advised to better understand this observed phenomenon. This study uses observations from building audits and modelling to establish an understanding of the operational performance in two case studies, following a calibration approach that was developed to minimise model uncertainties about energy end-uses in cooling-dominated data-poor environments. The findings indicate that low metered energy could be attributed to under-serviced indoor environments, with significant post-retrofit energy rebounds expected, reaching up to 295 % and 45 %, due to comfort-taking and following potential changes in building activity aligned with adaptive reuse plans. With energy rebounds expected to diminish the retrofit savings that could be achieved, the study discusses the implications for policy and decision-making in contexts where retrofit could be financially infeasible, yet required for health and wellbeing benefits, calling for alternative business models that can be more effective at incentivising retrofit uptake in similar contexts.

1. Introduction

The Egyptian government is relocating its headquarters to the New Administrative Capital, leaving behind a stock of public administrative buildings in Cairo, where extensive refurbishment and adaptive reuse are expected to take place (Hamouda, 2024; Salah, 2023; Werr, 2024). Aiming to optimise the benefits from the investments allocated for the upcoming interventions, it is crucial to understand the operational performance to support retrofit evaluation. While few studies provided estimates of retrofit outcomes in this building typology (A. Hamada et al., 2021; Hanna, 2015; The World Bank and ESMAP, 2017), the baseline models/benchmarks used were found to lack sufficient evidence on the operational conditions, casting doubts about the reliability of potential outcomes.

A. A. Hamada et al. (2025) spotted low metered energy consumption in a sub-stock sample of nine public administrative buildings subject to relocation, providing the first known empirical evidence that challenged common perceptions about this building portfolio often seen as 'energy intensive' (A. A. Hamada et al., 2025; The World Bank and ESMAP, 2017). The study called for further building-level investigation to better understand the operational performance and inform policymakers on how retrofit can be tailored to current operational conditions. Therefore, this study aims to improve our understanding of the operational performance through a case study approach, where building audits and modelling complement emerging stock-level evidence with building-level information.

Insufficient knowledge of buildings' operational performance can result in a performance gap, where the predicted post-retrofit energy use is not aligned with the actual metered consumption (Khoury et al., 2017). Although model calibration can help minimise this gap, validating the models solely against EUI benchmarks might not be sufficient to guarantee model representativeness of the reality (Jain, Burman, Davies, et al., 2020). Inaccurate loads and operating schedules may offset or cancel out each other, creating a correct calibrated energy use total that could lead to inaccurate retrofit recommendations (Karaguzel and Lam, 2011; Taheri et al., 2019). Model calibration challenges may also arise in cooling-dominated contexts in particular, where a single electricity meter is used to capture all the building loads combined and

* Correspondence to: Central House, 14 Upper Woburn Place, London WC1H 0NN, UK.
E-mail address: amr.hamada@ucl.ac.uk (A.A. Hamada).

https://doi.org/10.1016/j.egyr.2026.109066
Received 10 August 2025; Received in revised form 20 December 2025; Accepted 24 January 2026
Available online 30 January 2026

sub-metering lacks clear end-use association (Chae et al., 2016). Calibrating modelled against metered energy use might not be sufficient to consider the model reliable, as breaking down energy consumption by end-use improves understanding of the operational performance, hence can better inform retrofit recommendations (Kristensen et al., 2017).

Low metered energy in buildings can be attributed underutilisation, or inadequate conditioning, or lighting, rather than building efficiency (Guerra-Santin et al., 2017; Jain et al., 2020; Maghsoudi Nia et al., 2022). Matching modelled to actual energy use without capturing the operational conditions can lead to performance misinterpretation and to implementing measures misaligned with actual needs. For instance, envelope upgrades in under-serviced buildings will yield marginal savings, and installing efficient lighting in buildings that are mostly daylit will make minimal contributions to the energy savings (Duarte et al., 2015). Tools such as energy audits and space-use monitoring are therefore essential to find retrofit opportunities that stem from actual operational conditions (Jain, Burman, Stamp, et al., 2020; Shrubsole et al., 2019).

However, getting sufficient building data to understand the operational performance can be challenging. Detailed monitoring data availability is often constrained by limited accessibility and poor metering (Fabrizio and Monetti, 2015). Long-term, high-resolution monitoring is often infeasible due to time, cost, and expertise requirements (Miller et al., 2013). On the other hand, simple observations, such as walkthroughs, facility manager interviews, and publicly available imagery, can significantly improve model accuracy (Leroy et al., 2019), and incorporating uncertainty analyses can further strengthen model reliability when working with limited data (Yilmaz et al., 2021).

Therefore, this study adopts an audit-informed calibration approach to distinguish efficiency from other operational conditions leading to low energy use, and to provide projections for changes in baseline energy use that could occur when the buildings are renovated and reused. The study aims to establish reliable representations of operational energy that leverage audit observations and the data available in the public domain, to address uncertainty in data-poor environments, offering a modelling approach that can be especially effective in cooling-dominated and resource-constrained contexts where model calibration can be challenging.

2. Methods

Building energy audits took place in two public administrative case study buildings in Cairo. The audit data informed model development and calibration, which was supported by uncertainty analysis. Adjustments to the baseline models were applied to predict the potential changes in the buildings' indoor environment conditions and activity following business-as-usual renovations and adaptive reuse. The overall research flow for each case study is illustrated in Fig. 1.

Following the characterisation of a subset of the building stock presented in A. A. Hamada et al. (2025), two case studies were selected for building-level investigations though energy audits and modelling, named hereafter as MOJ (for the Ministry of Justice) and MOH (for the Ministry of Housing, Utilities, and Urban Communities), representing the authorities these buildings are currently affiliated with. The two cases had distinctive EUIs, positioned above and below the average metered EUI (70 kWh/m^2) obtained from the group of buildings studied in A. A. Hamada et al. (2025), aiming to investigate the operational conditions leading to their distinctive baseline performance.

The MOJ case is located in Cairo's Downtown district. It comprises 14 floors with a total gross floor area (GFA) of 45,725 m^2, shown in Fig. 2, and. Originally designed by architect Tawfik Abdel-Gawad in the 1960s, the previously Y-shaped building now includes an eastern extension/annex that was estimated to have been added in the 1990s. The building's measured annual energy use intensity (EUI) was 33 kWh/m^2, estimated based on meter readings taken in 2021 for the two electricity meters installed (no gas meters were found).

MOH, the second case, is the headquarters of the Ministry of Housing and Urban Development located in Cairo's Downtown district, with a 16,700 m^2 GFA spread over 16 floors as shown in Fig. 3. The building includes four podium floors: the ground floor features many service and storage spaces, while the floors from first to third accommodate top-level ministerial offices. While the podium is of a compact rectangular

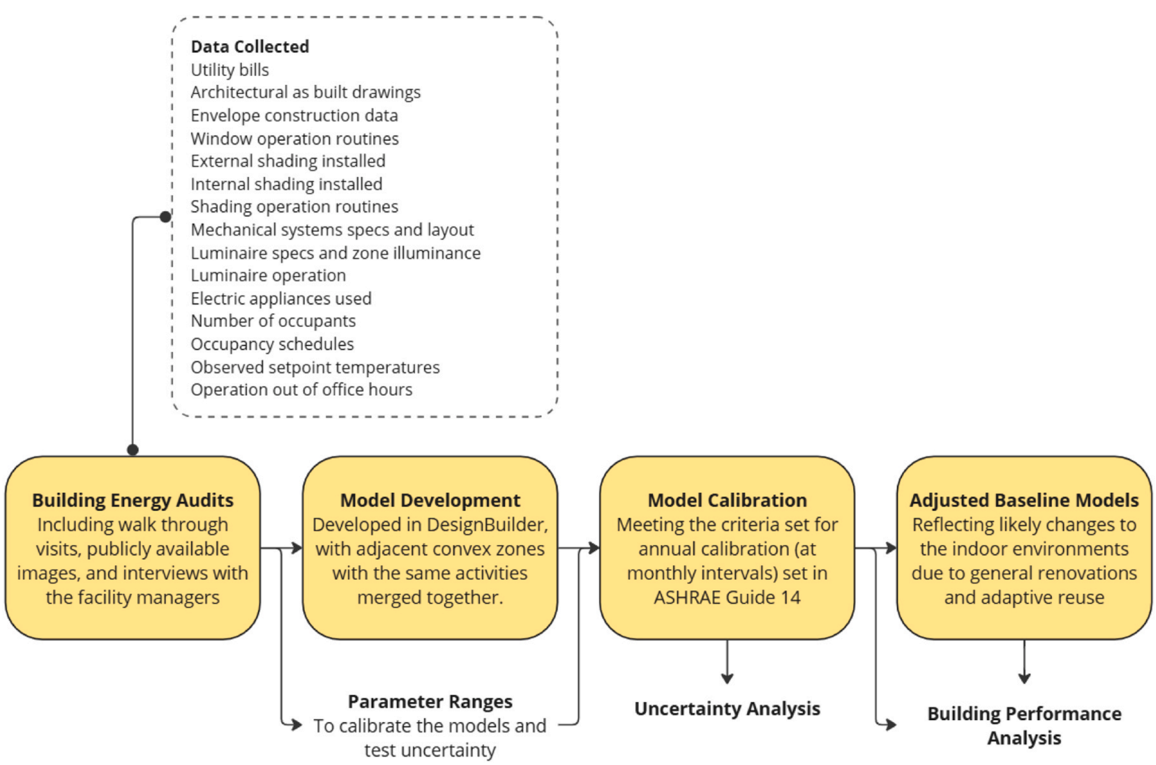

Fig. 1. Auditing and modelling workflow for the case studies.

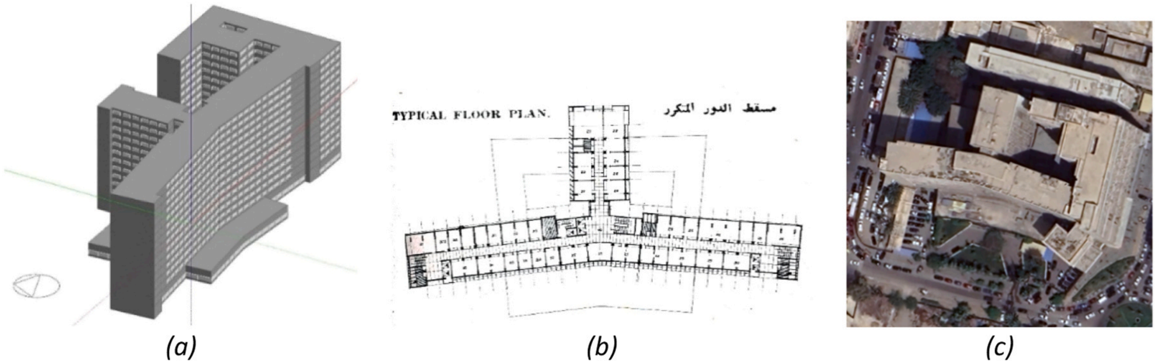

Fig. 2. (a) MOJ's energy model, (b) MOJ's typical floor plan before extension (Hammad, 1963), (c) MOJ's satellite image showing the eastern extension.

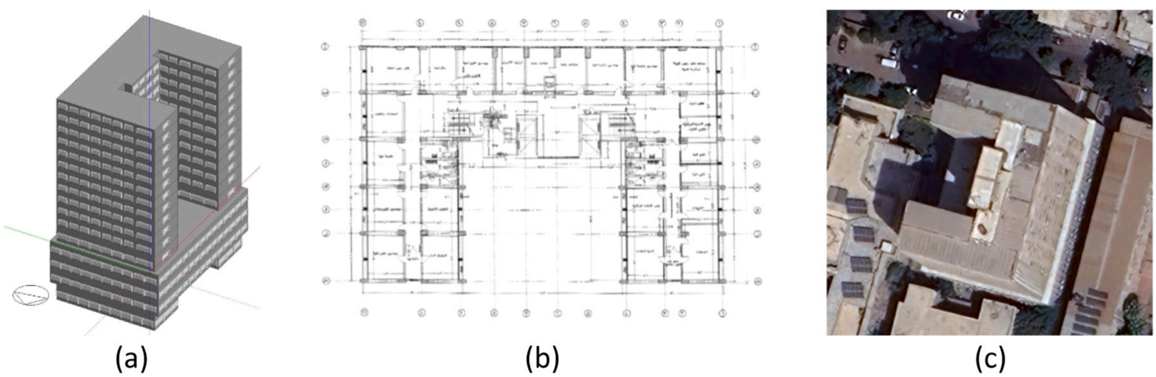

Fig. 3. (a) MOH's energy model, (b) MOH's typical floor plan, (c) MOH's Satellite image.

form, the remaining 12 floors follow a U-shaped symmetrical plan that entails double-loaded corridor offices with service cores located at the corridor intersections, as shown in. The building's measured EUI is approximately 107 kWh/m^2, estimated based on readings taken in 2021 for the four electricity meters installed, and no gas meters were found.

2.1. Audit methods

Audit activities included the following (with data sources detailed further in Table 8 in the appendices):

1. Revising the building's architectural and engineering drawing documents, and comparing them to as-built conditions.
2. Collating and analysing the metered annual utility bills, at monthly intervals.
3. Walking through the building, at least once in summer and winter, during occupancy hours, to make observations about the typical operational conditions of building elements and systems (i.e., movable shading, operable windows, measuring illuminance levels, lighting switches, electric appliances used, and HVAC controls).
4. Conducting interviews with the facility managers to obtain further information, especially for data that can hardly be observed in walkthrough visits, such as the operation schedules, number of occupants, seasonal operational schedule variations and adjustments for holidays, typical HVAC controls, etc.
5. Checking all satellite, exterior, and interior images of the buildings found in the public domain (e.g., Google Maps) to check the external HVAC components installed, rooftop photovoltaic installation, percentage of windows opened, the use of night lights, etc.
6. Checking the literature for subsidiary data to support typical assumptions of the models when building-specific information could not be otherwise obtained (i.e., performance of typical fabric elements, and typical infiltration rates).

It was essential to collect data from multiple sources to make informed assumptions about the operational conditions and compare conflicting data sources when possible. More details about the data sought from the energy audit activities/ sources of information are shown in Table 8 in the appendix, where data sources for each building element are ordered from most to least informative. Questions asked in the interviews conducted with the facility managers can be found in the Facility Managers (FM) Interview Forms section the appendices.

2.2. Model development and calibration methods

2.2.1. Model development

All baseline models were developed in DesignBuilder (Version 7.3.0), a user interface for the EnergyPlus simulation engine (Version 9.4.0). The models used typical weather data from Cairo International Airport's weather station, obtained from EnergyPlus' website. Given the large size of Cairo's public administrative buildings, and the space variabilities they incorporate, the models were simplified using the below conventional modelling procedures, ensuring that the architectural zones were thought of as thermal zones, to reduce computational expenses while preserving the model accuracy.

1. Categorising the zones into office (where occupants spend most of their time) and non-office zones (which include all circulation, storage, and toilet spaces).
2. Merging adjacent thermal zones that have the same activity, operational conditions, and orientation, by removing the partitions in between.
3. Modelling HVAC systems using EnergyPlus ideal loads objects (DesignBuilder's simple HVAC modelling) while using standard calculations for auxiliary energy components to account for fan and pump energy consumption. System coefficients of performance (COPs) were used to post-process the results.

4. Modelling all shading surfaces, characteristic to Cairo's public 1960s buildings, as window overhangs and fin surfaces not as complex EnergyPlus shading objects to minimise the computational expense of shading calculations.

Some building information could be directly obtained from the audits with a relatively low degree of uncertainty, such as building geometry, building fabric elements build-ups, typical operation schedules, and the types of cooling systems installed. Other building information could be obtained, but with a relatively high degree of uncertainty where personal interpretations were key in developing input assumptions (Fabrizio and Monetti, 2015; Raftery et al., 2011), such as building activity levels, control routines, and assumed internal gains. These inputs were deemed difficult to assume especially due to the large sizes of the buildings audited, the stochastic nature of occupancy and operation, and the limited context-specific evidence available on what assumptions could be typical or representative (Coakley et al., 2014; Raftery et al., 2011). Therefore, the modelling approach opted to use deterministic input variables for elements that could be directly estimated from the audits (i.e., fabric parameters), while the input variables that entail higher levels of uncertainty (i.e., internal gains) were tuned during an iterative calibration process that was supported by uncertainty analysis.

2.2.2. Model calibration

Calibration aims to ensure the model accurately represents the actual building performance by checking if the modelled and metered energy consumption data are aligned, within acceptable error thresholds. ASHRAE (2014) measures error thresholds through two indicators: coefficient of variance of root mean square error (CVRMSE) and normalised mean bias error (NMBE) (ASHRAE, 2014), both shown in Table 1. While the calibration criteria can be met via either monthly or hourly data, this study opted for the monthly criteria, as the metered data was billed monthly.

Meeting the calibration criteria alone was deemed insufficient for representing the actual operational conditions as the criteria could be met in many possible ways of adjusting some model parameters. Given that all end-uses were metered in one aggregated electricity meter, calibrating the sum of end-uses to the measured data in the absence of sub-metered end-uses might incorporate inaccurate representations of each end-use, causing major model discrepancies from real operational conditions. Therefore, the study developed a framework that aims to calibrate modelled end-uses to estimated metered end-uses, guided by an analysis of energy consumption patterns in Cairo's public administrative buildings in A. A. Hamada et al. (2025). Fig. 4 shows the estimated typical EUI breakdown by end-uses that characterises Cairo's public administrative buildings, concluded from A. A. Hamada et al. (2025), where the energy use in during winter was estimated to be solely attributed to two end-uses, lighting and electric plug loads. This meant that calibrating the energy consumption in winter months could lead to an estimate of cooling loads (the remainder in summer), given that lighting and plug loads would remain mostly consistent throughout the year. Lighting and plug loads could then be disentangled if one of them could be estimated through sufficient evidence from the building audits.

Model tuning during calibration followed the iterative sequence shown in Fig. 5. Lighting loads could relatively be easier to observe and quantify during the audits (compared to cooling and plug loads), by visually checking the luminaires installed, estimating their operation routine and measuring illuminance at desk level. Since the energy consumption in winter was found to be attributed to lighting and plug loads combined, uncertainties about plug loads could be narrowed by calibrating the model for the winter consumption (and given that lighting model inputs could be estimated). Cooling loads were defined as the remainder of the annual EUI after lighting and plug loads were removed. Modelled cooling loads could therefore be calibrated, by matching the model's energy consumption in the summer, leading to a full year model calibration.

Table 1
Acceptable error for model calibration according to ASHRAE Guide 14.

	Monthly data	Hourly data
CVRMSE	≤ 15 %	≤ 30 %
NMBE	≤ ±5 %	≤ ±10 %

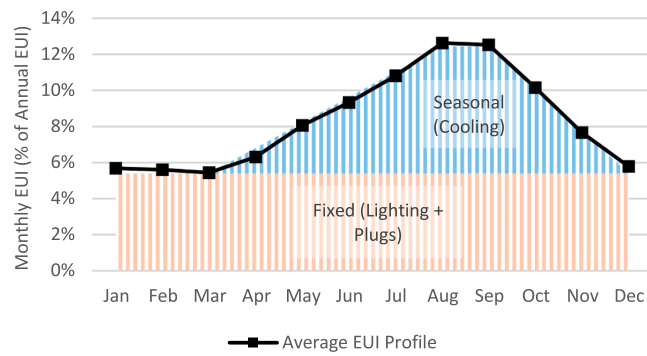

Fig. 4. End-use evaluation for an average EUI profile (A. A. Hamada et al., 2025).

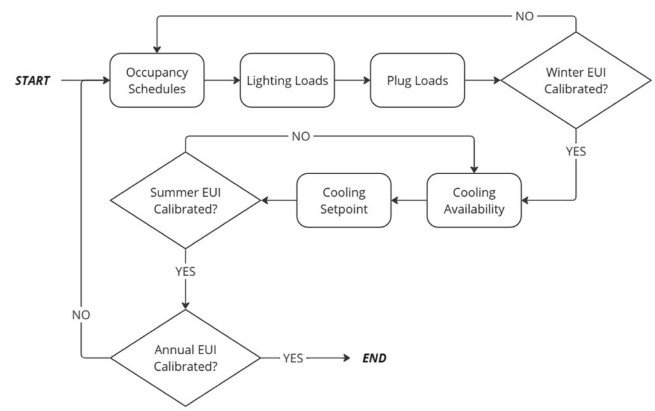

Fig. 5. Iterative parameter tuning during the calibration process.

Although some office spaces in the buildings were observed not to be air-conditioned, it was challenging to model the unique zone-specific HVAC conditions, given that each building included hundreds of office spaces. Therefore, all office spaces were modelled as air conditioned, where adjacent offices with the same orientation merged into one thermal zone, but the modelled cooling setpoint temperature was tuned until the modelled cooling loads matched that estimated from the energy bills. The cooling setpoint acted as a proxy for the actual percentage of cooled office area coverage. This approach followed studies and calibration methodologies that identified HVAC setpoint tuning as a practical proxy for the extent of mechanical cooling delivered during typical operation, allowing the simulation to match metered consumption by accounting for unobserved patterns of partial cooling, shifting occupancy, or non-operational systems (Coakley et al., 2014; Pachano et al., 2023; Raftery et al., 2011).

Adjustments to occupancy schedules, in the range of 0–5 % during holidays and out of occupancy periods, and reductions by up to 20 % and up to 2 h during Ramadan, were assumed to calibrate activity levels to match the metred data, estimated based on the facility managers' feedback.

2.3. Model adjustment methods

Model adjustments in this study refer to necessary or expected changes in the buildings' operational characteristics that would affect the energy consumption, potentially offsetting the savings perceived/metered in the post-retrofit stage. Several adjustments were applied to the baseline models to account for (1) the required indoor environmental quality improvements to reach standardised conditions and (2) the predicted adjustments for building occupancy and operation due to adaptive reuse.

As both adaptive reuse (change of building use) and energy retrofit interventions could be coupled together towards reaching a post-retrofit stage, adjusted baselines act as a theoretical/transitional stage that will not be metered or quantified, as illustrated in Fig. 6, aiming to disentangle the impact of changes in the operational conditions from the impact of energy retrofit. Model adjustments are used to quantify potential baseline energy rebounds, to assess retrofit effectiveness in isolation from the impact of changes in the building's use and the indoor environment.

The study opted for implementing the following adjustments, detailed further in the following paragraphs and in Table 2:

- Required adjustments: to ensure indoor environmental quality by improving lighting illuminance levels to meet ISO-EN 12464 and improving thermal comfort by making all office spaces air conditioned.
- Predicted adjustments: to account for a conversion from public administrative functions into a private sector offices, which entails assumptions for plug load increases due to increasing computer usage, and extended occupancy schedules.

Since non-office spaces, including toilets and circulation spaces, were merged in the model, area-weighted illuminance levels of 120 lux were assumed based on an interpolation of ISO- EN 12464 target illuminance for toilets (150 lux) and circulation spaces (100 lux). HVAC coverage was still excluded from circulation and service spaces according to ASHRAE 55 Guidelines that denote that indoor thermal comfort standards can be omitted in spaces where occupants stay for 15 min or less (ASHRAE, 2013).

It was acknowledged that many adaptive reuse scenarios, besides the office building scenario, could be proposed, such as hotels, research centres, hospitals, mixed-use, etc. However, the study opted for testing an office building adaptive reuse scenario as other scenarios would entail a lot of uncertainty about the changes in occupants' density, occupancy schedules, HVAC systems, and plug loads to correspond to the building's new functions, which requires further support from empirical contextual/local operational building performance data to minimise such uncertainties. In contrast, office building functions are similar to public administrative ones, with minimal adjustments, and their operational performance in Egypt has been benchmarked in the literature (Elharidi et al., 2017, 2018).

The rationale for occupancy and plug load adjustments is backed by the notion that public sector employees in Egypt typically work less hours than the private sector ones as public buildings typically in Egypt

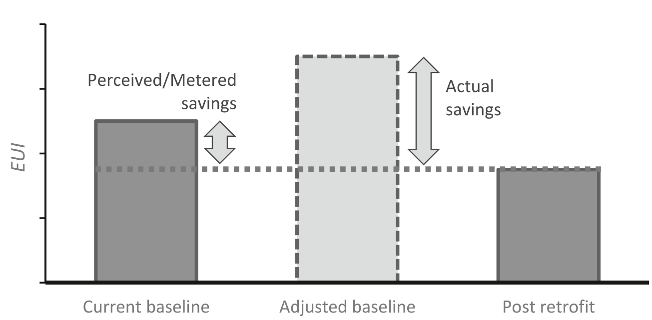

Fig. 6. Illustration of using baseline adjustment to evaluate actual and perceived retrofit effectiveness.

Table 2
Adjustments applied to the case studies.

	Code	*Scope*	*Assumed conditions*
Required	*L*	*Lighting*	The application of ISO- EN 12464 standard for lighting: Target illuminance in office zones = 500 lux Target illuminance in non-office zones = 120 lux
	C	*Cooling*	100 % of the office spaces are cooled @ the setpoint tuned in the calibrated models (24 °C)
	H	*Heating*	100 % of the office spaces are heated @ 21 °C
Predicted	*P*	*Plug loads*	80 % of the occupants use desktop computers
	O	*Occupancy*	Using a standard ASHRAE 90.1 office occupancy schedule template

typically run from 8:00–15:00 while private offices run at least from 9:00–17:00 and many of them can overrun until 19:00. Moreover, taking public holidays off is by law strictly maintained in the public sector, but is not as enforced in the private sector (Assaad, 2014; Shahen et al., 2020). Therefore, a typical ASHRAE occupancy schedule for offices, adjusted for Egypt's Sunday to Thursday weekday schedules, can be used to reflect typical office hours, as shown in Table 9 in the appendices.

With regard to plug load adjustments, the plug loads in private sector offices surveys conducted by Elharidi et al. (2017), (2018) were found to be higher than those quantified in the public sector offices obtained from the building audits conducted in this study. Computer use was a major distinction, supported by the audit data analysed in our study, and the literature-based evidence which suggests that the public sector in Egypt is deemed unattractive to relatively highly educated skilled workers (Gindling et al., 2020), causing performance imbalances and the workforce distortions (Assaad, 2014; Gindling et al., 2020; Shahen et al., 2020). As a result, the plug load assumptions were adjusted in the study to reflect an increase in computer acquisition among the building occupants of private offices, reaching 80 % of the occupants, while the use of other appliances was assumed to remain consistent.

3. Results

The results section presents the building audits, model calibration, and model adjustment results.

3.1. Audit findings

3.1.1. Audit findings in MOJ building

Electricity bills for MOJ, from December 2020 to November 2021, are shown in Fig. 7(a), with metered data presented, but not to be associated with specific end-uses. Fig. 7(b) shows the monthly EUI, after interpolating meter readings based on the reading dates, to represent the monthly EUI per calendar month. Seasonal EUI patterns in MOJ were found consistent with the average annual EUI profile (percentage of monthly EUI to annual EUI) obtained from the nine-building dataset analysed in A. A. Hamada et al. (2025).

Minimum and maximum input parameter ranges for building systems and internal gains to be used for model calibration were obtained from the audits. Luminaires were estimated to provide average illuminance of 100 and 200 lux in office and non-office spaces respectively, where combinations of T8 fluorescent lamps (found in 80 % of the luminaires) and LEDs (in 20 % of the luminaires) were observed during the building visits. These assumptions led to an estimated overall assumption of lighting efficacy range of 4.02–4.40 W/m^2 per 100 lux. Despite the varying lighting controls across the different building floors, it was estimated – based on the building visits and the facility manager's feedback – that 50–75 % of the lights in non-office/circulation spaces were switched off.

The facility manager noted the difficulty in estimating the number of occupants, where a large percentage of employees do not have dedicated

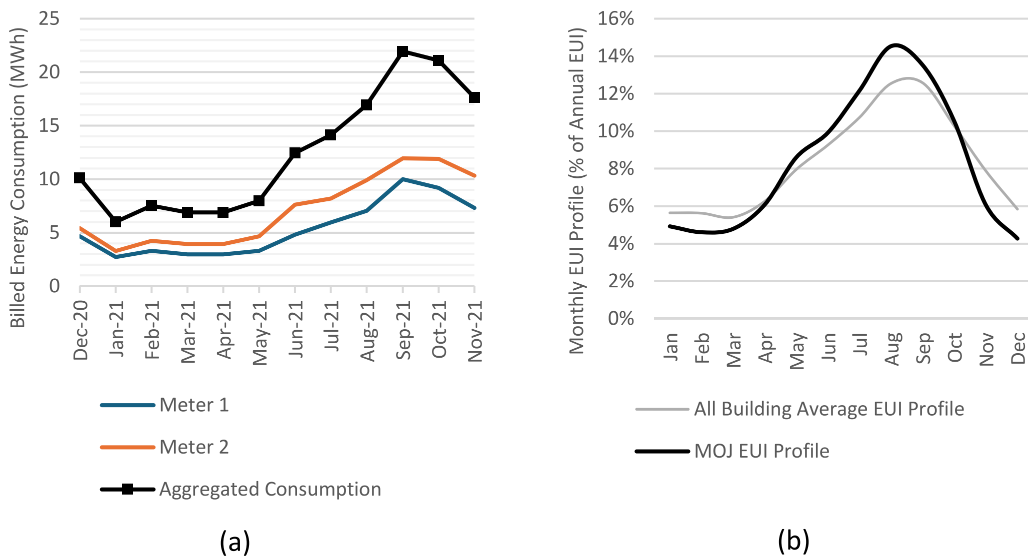

Fig. 7. (a) Metered bills in MOJ, (b) MOJ EUI profile compared to the average EUI profile in the sub-stock data.

office hours, as many of the occupants were part-time experts or consultants who have dedicated offices in the ministry but not used on a daily basis. The facility manager suggested that the building was expected to accommodate about 3000–3700 employees, leading to a maximum estimated occupancy density of approximately 0.08 person/m^2.

It was estimated that plug loads could be relatively low, as computers/screens were observed as rarely used among employees. Assumptions about the appliances' density across the building, including their powers and observed usage frequency, were established through a bottom-up approach, as shown in Table 3. After aggregating all plug load components, the equivalent overall normalised power density for electric plug loads was found to be within the range of 3.51–6.15 W/m^2, with computers estimated to have the largest contribution to these loads.

While rooftop units were used to cool the offices located in the building podium, the rest of the building used a combination of terminal cooling units and electric fan ventilation. Observations during the summer 2022 walkthrough estimated that 60–70 % of the offices areas, particularly those occupied by junior employees, were not equipped with mechanical cooling equipment, relying solely on ceiling/desktop fans and window ventilation. This was verified through publicly available satellite and street view images of the building, where external cooling units (the compressors units of zonal split cooling equipment) were counted and compared to the number of zones they serve, estimating the area range of offices that are unlikely to be mechanically cooled. Finally, the parameter ranges established during the audits in MOJ (for occupancy, lighting, plug loads, and cooling) were used to calibrate the model in the next step of the study.

3.1.2. Audit findings in MOH building

Similar to MOJ, a twelve-month utility bill record was obtained for MOH between December 2020 to November 2021. Fig. 8(a) shows the aggregated consumption based on the readings obtained in the four electricity meters installed. Meter readings were interpolated based on the reading dates to represent the energy use per calendar month. Fig. 8 (b) shows the EUI profile in MOH in comparison to the average EUI in the collected data.

Field visits highlighted that all luminaires were switched on in all office spaces, and in most corridors and hallways. With fluorescent tube luminaires installed, the normalised lighting power density (luminaire efficacy) was estimated to be 4.40–4.80 /m^2 per 100 lux, and providing estimated average illuminance levels of about 400 and 200 lux in office and non-office, respectively, based on illuminance measurements taken at desk-level in eight different zones in the building.

Table 4 shows the audit findings with regard to plug loads, following the same approach adopted in MOJ. Most of the employees, estimated to be 50–70 % of the building occupants, were observed to have fixed desktop computers. This was a major component in determining the potential plug loads that were estimated to account for 7.40–11.10 W/m^2. By aggregating the estimated appliance load densities, the resultant normalised plug loads' power density was estimated to range between 9.0 and 12.7 W/m^2.

Regarding the HVAC system configuration, the podium was highly reliant on central cooling (VAV system) while the 12 upper floors were mostly air-conditioned using terminal (zonal) split units. The interview with the facility manager indicated numbers and the different capacities of the zonal cooling units installed, where it was estimated that 75–90 % of office areas have active cooling installed, but information on the cooling coefficients of performance could not be obtained.

Table 3
Plug load estimates in MOJ.

Item	*Power (W)*	*Operation frequency*	*Use density*	*Equivalent Power Density (W/m^2)*
Computers	150	During full occupancy hours	25–40 % of people use one	2.46–4.79
Kettles	2500	One minute per hour of occupancy time	1 per 10 occupants	0.27–0.33
Photocopy (standby mode)	50	During full occupancy hours	1 per 40 occupants	0.08–0.10
Photocopy (functioning)	500	One minute per hour of occupancy time	1 per 40 occupants	0.013–0.016
Television	60	During full occupancy hours	1 per 50 occupants	0.079–0.10
Fridges	150	All day	2 per floor (3200 m2)	0.45
Phone chargers	30	One hour per day	50 % of people use one each	0.16–0.20
Total				3.51–6.15 W/m^2

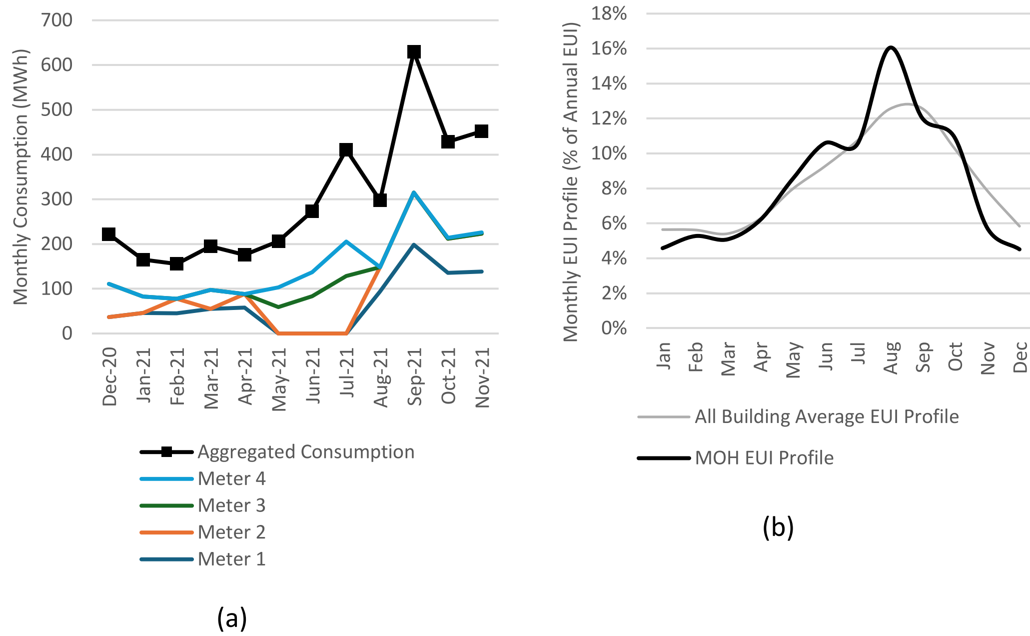

Fig. 8. (a) Metered bills in MOH, (b) MOH EUI profile compared to the average EUI profile in the sub-stock data.

Table 4
Plug load estimates in MOH.

Item	*Power (W)*	*Operation frequency*	*Use density*	*Equivalent Power Density (W/m^2)*
Computers	150	During full occupancy hours	50–75 % of people use one each	7.40–11.10
Kettles	2500	One minute per hour of occupancy time	1 per 10 occupants	0.41
Photocopy (standby mode)	50	During full occupancy hours	1 per 40 occupants	0.12
Photocopy (functioning)	500	One minute per hour of occupancy time	1 per 40 occupants	0.02
Television	60	During full occupancy hours	1 per 50 occupants	0.12
Fridges	150	All day	1 per floor (1040 m2)	0.69
Phone chargers	30	One hour per day	50 % of people use one each	0.24
Total				9.0–12.7 W/m^2

3.1.3. *Building fabric data*

Assumptions of the building fabric in both buildings could be estimated with a relatively higher degree of certainty, compared to building systems and internal gains which are often considered more challenging to observe and quantify (Coakley et al., 2014; Fabrizio and Monetti, 2015). Table 5 summarises the deterministic parameter values assumed for other building performance data, including the building fabric, estimated mainly based on the architectural drawings and the field visits implemented as part of the building audits – except airtightness that was obtained from the literature.

3.2. *Calibration results*

3.2.1. *Calibration results in MOJ building*

Using the parameter ranges established through the building audits, and following the iterative calibration approach illustrated in Fig. 5, the baseline model for MOJ was calibrated – reaching a simulated annual EUI of 32.42 kWh/m^2 (metered EUI = 33.23 kWh/m^2). The resultant monthly normalised mean bias error (NMBE) value was 1.6 % (< 5 % acceptable threshold), and the coefficient of variance for root mean square error (CVRMSE) was only 12.5 % (< 15 % acceptable threshold). Fig. 9 illustrates the comparison between the modelled and metered energy.

The parameter values shown in Table 6 were used to achieve successful calibration. Medium lighting power densities (LPD) and low plug load densities were opted for to meet the calibration requirements in the winter months. Low occupancy adjustments were used in most inputs, as successful calibration was met following 0 % of occupancy after typical working hours and on the weekends. The number of hours worked in Ramadan was reduced by one hour, with no occupancy during Eid periods assumed.

With winter months calibrated using the model input assumptions reached, cooling loads could be estimated, as the remainder from the energy use when other end-uses were excluded. MOJ percentage of cooled offices were determined via iterative changes in cooling setpoint, as proxy for cooling area coverage, until the simulated cooling consumption matched the metered one.

The model was successfully calibrated with all office spaces assumed to be cooled at a setpoint of 28 °C. Given that 30–40 % of the offices were actually cooled from the audits, the cooling setpoint was estimated to be about 23 °C to 24.5 °C (or 36 % of the offices cooled at 24 °C, deterministically) as per the model-based curve shown in Fig. 10, where pairs of setpoint and percentage of cooling datapoints associated with the same cooling energy use. With all end-uses calibrated successfully, the EUI breakdown by end-use in MOJ was estimated to be 38 %, 22 %, and 40 % for lighting, plug loads, and cooling, respectively.

3.2.2. *Calibration results in MOH building*

The baseline model for MOH was calibrated, reaching a simulated annual EUI of 108.14 kWh/m^2, compared to a metered EUI of 107.42 kWh/m^2 – as shown in Fig. 11. The monthly normalised mean bias error (NMBE) was 0.66 % (< 5 % acceptable threshold) and the coefficient of variance for root mean square error (CVRMSE) was only 10.56 % (< 15 % acceptable threshold). The metered and simulated EUI data are

Table 5
Building elements description and assumed performance in both buildings based on the audits.

Building Element	*Assumed Performance*	*Description*
External Walls	U-Value = 2.06 W/m²K	Internal 2.5 cm wet cement plaster. 25 cm fired clay solid bricks, with 1 cm mortar in grooves. External 2.5 cm wet cement plaster.
Internal Walls	U-Value = 2.949 W/m²K	2.5 cm wet cement plaster. 12 cm fired clay solid bricks, with 1 cm mortar in grooves. 2.5 cm wet cement plaster.
Roofs	U-Value = 0.545 W/m²K	Internal 2.5 cm wet cement plaster. 15 cm reinforced concrete flat roof. Jute sheets for moisture protection. 5 cm expanded polystyrene insulation. Average 7.5 cm aerated concrete, sloped at 1/100 for rain drainage. 6 cm sand bedding. 2 cm cement mortar. 2 cm cement tiles.
Ground Floors	U-Value = 0.95 W/m²K	10 cm of plain concrete. Jute sheets for moisture protection. 15 cm of reinforced concrete. 6 cm sand bedding. 2 cm cement mortar. 2 cm marble tiles.
Internal Floor	U-Value = 1.428 W/m²K	2.5 cm wet cement plaster. 15 cm of reinforced concrete. 6 cm sand bedding. 2 cm cement mortar. 2 cm marble tiles.
Glazing	U-Value = 5.82 W/m²K SHGC = 0.86	Single glazing, 5 mm thick
Airtightness	6.14 ACH @ 50 Pa	Assumed based on Raafat et al. (2023)
Window Frame	U-Value = 5.84 W/m²K	A frame and one divider of uninsulated aluminium profile, 4 cm wide.
External Shading	All windows (except north-facing) shaded with 40–60 cm deep horizontal overhangs and side fins.	
Internal Shading	Most windows observed to have movable internal blinds installed (slates). Blinds were added in the model to all windows and where assumed to be dropped (used) when the indoor temperature exceeds 24 °C.	

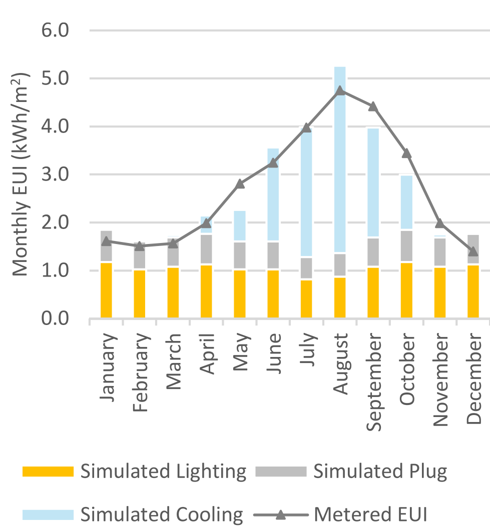

Fig. 9. Monthly energy use intensity in MOJ by end-use.

shown in Fig. 11. Parameter values shown in Table 7 were assigned to the model variables associated with lighting, plug loads, and occupancy to reach successful calibration. Relatively higher parameter values, compared to MOJ, were opted for to calibrate the model, indicating that

Table 6
Calibration parameters for MOJ.

Calibration parameter	*Lower bound*	*Upper bound*	*Calibrated value*
LPD in office spaces (W/m²)	8.0	8.80	8.40
LPD in non-office spaces (W/m²)	4.0	4.40	4.20
Plug load (W/m²)	3.51	6.15	3.60
Office areas with mechanical cooling (%)	30	40	36
Occupancy after office hours (%)	0	5	0
Occupancy on weekends (%)	0	5	0
Reduction in Ramadan office hours (hrs)	2	0	1
Occupancy utilization in Ramadan (%)	80	100	100
Occupancy factor in Eid Al-Fitr (%)	0	5	0
Occupancy factor in Eid Al-Adha (%)	0	5	0

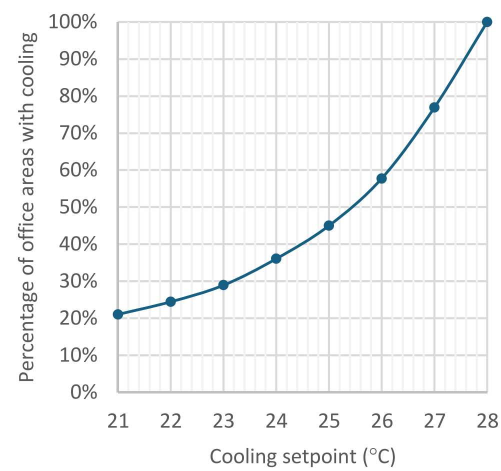

Fig. 10. Cooling setpoint temperatures as proxy for the percentage of the cooled office area in MOJ.

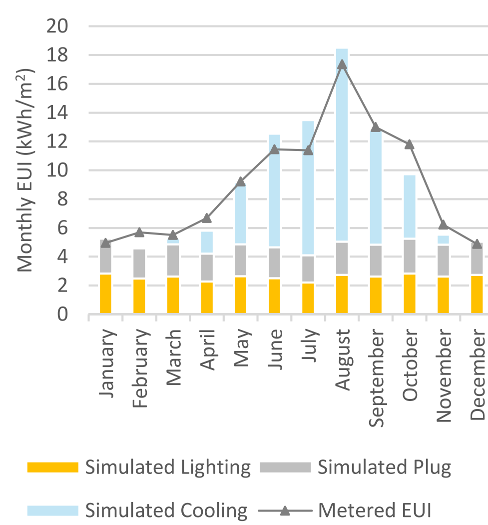

Fig. 11. Monthly energy use intensity in MOH by end-use.

higher internal gains are correlated with a higher baseline metered EUI.

After EUI during winter months was calibrated, cooling load in MOH could be estimated, which was significantly higher than in MOJ due to the larger uptake of mechanical cooling in MOH concluded from the audits. The percentage of cooled offices was determined by changing the cooling setpoints iteratively until the calibration requirements were met

Table 7
Calibration parameters for MOH.

	Lower bound	*Upper bound*	*Calibrated value*
LPD in office spaces (W/m^2)	17.60	19.20	18.0
LPD in non-office spaces (W/m^2)	8.80	9.60	9.0
Plug load (W/m^2)	9.0	12.70	12.70
Office areas with mechanical cooling (%)	75	90	78
Occupancy after office hours (%)	0	5	4
Occupancy on weekends (%)	0	5	4
Reduction in Ramadan office hours (hrs)	2	0	2
Occupancy utilization in Ramadan (%)	80	100	100
Occupancy factor in Eid Al-Fitr (%)	0	5	0
Occupancy factor in Eid Al-Adha (%)	0	5	0

during the summer. The model was successfully calibrated with all office spaces cooled at a setpoint of 25 °C, which was equivalent to nearly 80 % of the office spaces cooled at 24 °C, as shown in the model-based setpoint/cooled office area curve shown in Fig. 12. After all end-uses were calibrated successfully, the estimated EUI breakdown by end-use in MOH was found to be 31 %, 26 %, and 47 % for lighting, plug loads, and cooling, respectively.

3.2.3. Calibration uncertainty evaluation

To evaluate the calibrated models' uncertainties, simulations using the lower and upper parameter bounds assumed for model the inputs established during the building audits were evaluated. Fig. 13 shows the sensitivity and the overall uncertainty of modelled EUI that resulted from the input parameter ranges. The 100 % line represents the EUI obtained from the calibrated parameter values, showing the relative location of calibrated EUI within the whole min/max range that could be obtained.

Analysing uncertainty shows that uncertainties about lighting assumptions had a negligible impact on EUI evaluations, with a narrow range for lighting bounds assumed and asserting that lighting use can be relatively easy to quantify from audit observations. On the other hand, assumption for plug load and occupancy schedules resulted in slightly broader ranges of uncertainties. Summing all sources of uncertainty, by using all upper-bound parameter values, was shown to increase the total EUI by 32 % and 5 % above the calibrated 100 % value in MOJ and MOH, respectively, while using all lower-bound parameter values

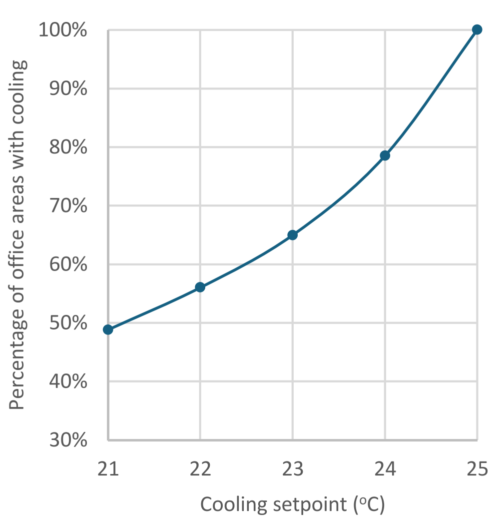

Fig. 12. Cooling setpoint temperature as proxy for the percentage of the cooled office area in MOH.

resulted in EUI drops of 9 % and 13 % below the calibrated 100 % EUIs in MOJ and MOH, respectively.

3.3. Adjustment results

Building audits and model calibration showed that public administrative buildings can be under-serviced, where a percentage of office spaces could lack air conditioning and sufficient lighting. Using the calibrated models, combinations of baseline adjustments were applied to the two case studies to quantify the changes in the baseline consumption that would result from required upgrades in indoor environmental quality and predicted changes in the building activity. Fig. 14 shows the adjustment results for the range of adjustments defined earlier in Table 2.

EUI adjustments in MOJ and MOH resulted in considerable EUI increases attributed to changes in cooling **(C)**, heating **(H)**, lighting **(L)**, plug loads **(P)**, and occupancy schedules **(O)**. For MOJ, the baseline EUI of 32.90 kWh/m^2 was projected to increase to 57.15 kWh/m^2 (a 74 % rise) when all office spaces are cooled, and up to 129.86 kWh/m^2 (a 295 % rise) when all adjustments were applied. In MOH, that was characterised by a higher existing EUI baseline, the EUI increased by 9 % to 117.56 kWh/m^2 following cooling adjustments, and up to 155.45 kWh/m^2 (a 44 % rise) with full adjustments. Results for all other adjustments (heating, lighting, plug loads, and occupancy schedules), with the results for all adjustment combinations shown in the detailed figures.

It was observed that EUI would rebound as a result of standard IEQ upgrades, by increases of 184 % and 34 % in MOJ and MOH, respectively, showing that buildings with a lower existing EUI baseline can be more subject to such rebounds, and meaning that the low baseline energy use was associated with under-serviced indoor environments, that should be distinguished from energy efficiency.

Such rebounds were expected to be exacerbated further when retrofit is coupled with adaptive reuse, where the building conversion into private sector offices was tested, following relevant occupancy schedule adjustments (O) and increases in the computer/screen use (P), as assumed earlier in Model Adjustment Methods. In that case, EUI increases of up to 295 % and 44 % were evaluated in MOJ and MOH, respectively, when all required and predicted adjustments were combined.

4. Conclusion

4.1. Summary of findings

The study provides evidence-based baseline performance analysis in Cairo's public administrative buildings, aiming to support retrofit decisions integrated into the adaptive reuse expected to take place following the government's relocation to the New Administrative Capital. By conducting energy audits in two cases with distinctive baseline conditions, and calibrating their energy models, the findings provide novel understanding of the operational performance, and evaluate potential energy rebounds from anticipated changes in the indoor environments.

With acknowledgement of the benefits from having robust data with high temporal and spatial resolutions, the study shows that acceptable understanding of the buildings' operational performance can still be established via more accessible means, such as walk through observations, interviews with facility managers and consulting other data sources available in the public domain. On the other hand, meeting the model calibration criteria was deemed insufficient for model validity, as more stringent validation against the estimated end-uses, rather than the aggregated metered consumption, was adopted for being more effective at providing reliable estimates of retrofit impacts that are well-aligned with baseline conditions.

The study underscored the need for carefully planned retrofit strategies that aim to balance energy savings with occupants' health

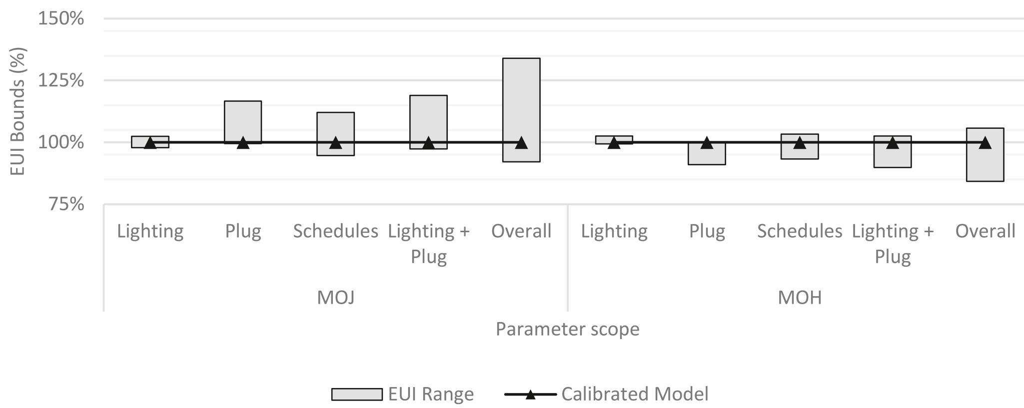

Fig. 13. Calibration uncertainty evaluation.

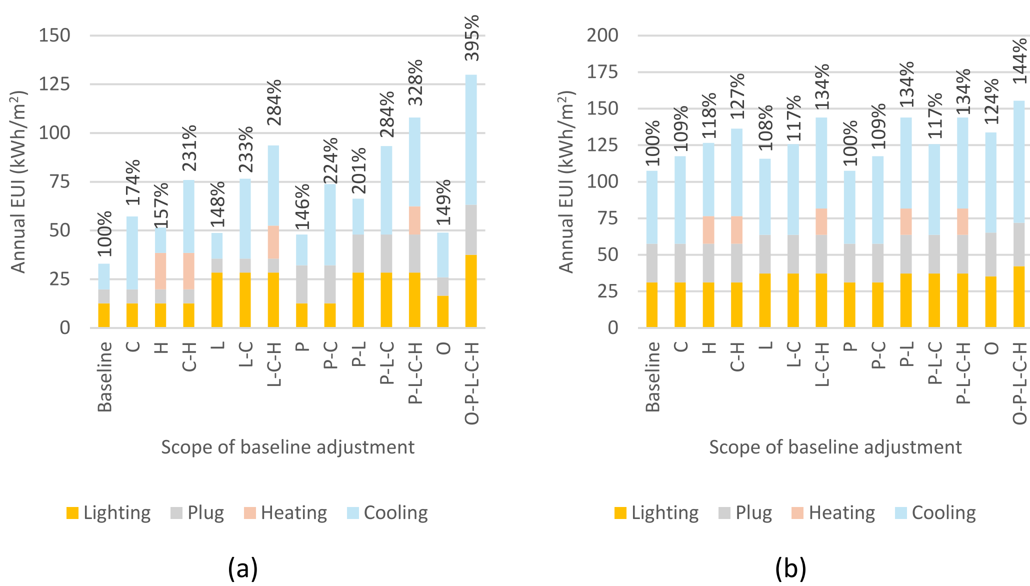

Fig. 14. End-uses of adjusted baseline EUI in MOJ (a) and MOH (b).

wellbeing. The concept of baseline model adjustment was proposed to distinguish between actual and perceived/metered retrofit savings. The methods developed in this study provide policymakers with a conceptual framework for optimising energy interventions while considering rebounds that might be required to improve IEQ.

The findings revealed that the low energy consumption spotted in Cairo's public administrative buildings is expected largely associated with under-serviced indoor environments, rather than energy efficiency.

Key model results included:

- **Calibrated IEQ baseline conditions in the two audited buildings:**

- **Lighting –** evaluated illuminance levels in the two cases were 200 lux and 400 lux in office spaces, contributing to lighting power densities (LPD) of 8.4 W/m^2 and 18 W/m^2, and 100 lux and 200 lux in non-office spaces, contributing to a LPD of 4.2 W/m^2 and 9 W/m^2, respectively.
- **Air conditioning –** it was estimated that about 36 % and 80 % of the office spaces were mechanically cooled in MOJ and MOH, respectively, with the model-obtained cooling setpoint estimated to be 24 °C, with the percentage of baseline cooling coverage causing a significant distinction in the projected post-retrofit rebounds attributed to comfort-taking in the two cases.

- **Energy breakdown by end-use the calibrated models:**
  It was estimated that the energy breakdown was 38 %, 22 %, and 40 % for lighting, plug loads, and cooling – respectively in the building of relatively low EUI (MOJ), and 31 %, 26 %, and 47 % for lighting, plug loads, and cooling for the building of relatively high EUI (MOH).
- **This low energy consumption can be primarily attributed to substandard IEQ:**
  Auditing and calibration in the two cases indicated that the low baseline energy consumption identified was mainly attributed to insufficient lighting illuminance levels and the lack of air conditioning coverage in all office spaces. With plug loads estimated to be sensitive to the number of screens used in the buildings, low electric plug loads contributed significantly to the low energy use due to the paper-based work still maintained in some governmental offices in Egypt.
- **Predicted increase in baseline energy use:**

Adjusting for improved IEQ and the adaptive reuse of the buildings as private offices could lead to 295 % and 44 % increases in energy consumption in the two case studies with relatively low and high baseline EUIs. These adjusted scenarios highlighted that buildings with relatively high existing baseline consumption might be less prone to energy rebounds resulting from projected renovations, as the low baseline energy use is attributed to substandard indoor environmental quality rather than energy efficiency.

4.2. Implications

The modelling and calibration methodologies adopted in the study provide practical approaches for minimising model uncertainties, especially when the buildings' operational data is limited. The methodological framework developed has implications beyond the Egyptian context, as the research indicates that the performance gap between predicted and actual energy consumption is a global issue, with buildings typically consuming more energy than predicted (Li et al., 2023). The study's approach in distinguishing between actual efficiency from substandard baseline indoor environmental conditions provides a basis for addressing similar challenges in other developing contexts where buildings are under-serviced.

The study suggested significant implications for retrofit policy and practice in contexts where buildings exhibit substandard baseline indoor environmental conditions. Understanding that low energy consumption can mask poor IEQ, rather than indicating efficiency, challenged conventional energy-centric retrofit evaluation frameworks and necessitates fundamental shifts in policy approaches. The magnitude of energy rebounds identified, reaching up to 295 % and 45 % in the case studies, demonstrated that traditional retrofit evaluation methods will systematically underestimate or entirely miss significant post-retrofit rebounds.

The rebounds spotted could also push for novel financing models that move beyond traditional energy savings-based approaches. The study's findings support the development of financing mechanisms that can capture broader value propositions. Therefore, new approaches to retrofit funding could be explored, such as:

- **Monetising health benefits**: Given the well-established links between poor air quality, inadequate lighting, and thermal discomfort with adverse health outcomes, the health benefits of improved IEQ could be used to justify retrofits. This includes reducing mortality and morbidity from air pollution-related illnesses and enhancing productivity by improving the working environment.
- **Energy infrastructure investment reallocations**: Investigating the impact of redirecting investment from expanding energy generation and distribution infrastructure towards retrofitting buildings expected to experience substantial energy demand growth. This can be particularly applicable in developing countries where energy infrastructure growth is projected to cater for essential improvements in the existing substandard indoor environment.
- **Carbon taxation instruments**: Leveraging carbon taxation schemes to incentivise the implementation of energy efficiency measures when the cost of not doing so would be higher.

4.3. Limitations and future work

This study faced some limitations. For instance, model calibration was based on monthly, building-level electricity consumption and audit-derived end-use estimates rather than high-resolution sub-metered data, limiting the precision of end-use disaggregation and operational characterisation. Simplified representations of zoning, HVAC systems and shading were required to maintain tractability for large and complex buildings, constraining the capture of spatial and system-level characteristics. Partial cooling coverage was represented through calibrated cooling setpoints, which provides a pragmatic but indirect approximation of actual HVAC operation.

The analysis is based on two large public administrative buildings selected to reflect the upper and lower bounds of the stock's EUI distribution; but inferring the results to the rest of the stock can require further building data and analysis. Only a private-office adaptive-reuse scenario was considered as uncertainties related to occupant behaviour, equipment efficiencies and system performance persist when further adaptive reuse scenarios are investigated.

Future work should prioritise expanding the evidence base on operational performance and energy use in Cairo's public and commercial building stock. The collection of higher-resolution electricity data, supported by targeted end-use sub-metering and short-term indoor environmental quality monitoring, would improve calibration robustness and end-use attribution. Incorporating spatially resolved and stochastic occupancy data would further strengthen representation of actual operational conditions. Machine learning methods can be used in building audits, i.e., by processing images of the buildings available in the public domain, to evaluate building operational conditions even when the data available is insufficient.

Further research should examine a wider range of adaptive-reuse scenarios using context-specific operational assumptions, alongside longitudinal monitoring of buildings undergoing retrofit or adaptive reuse to assess realised performance outcomes. Integrating economic, health and productivity considerations into evaluation frameworks would enhance the reliability and policy relevance of retrofit evaluations implemented in these buildings.

CRediT authorship contribution statement

Amr Auf Hamada: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sung-Min Hong:** Writing – review & editing, Supervision. **Rokia Raslan:** Writing – review & editing, Supervision, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices

Data Sources and Additional Assumptions

Table 8
Data gathered in energy audits and their sources

Scope	Information	Audit activity/ data source
Geometrical information	As-built architectural layout.	Drawing archives- walk-through observations- satellite images
	Number of floors	Drawing archives- walk-through observations- elevation images
	Building area	Drawing archives- walk-through observations- satellite images- interviews
	Uses of the different spaces	Drawing archives- walk-through observations- interviews

(continued on next page)

Table 8 (*continued*)

Scope	Information	Audit activity/ data source
	Window to wall ratio	Drawing archives- walk-through observations- elevation images
	Window reveal dimensions	Drawing archives- walk-through observations
	Operable area of windows	Walk-through observations- interviews- elevation images
	Fixed shading dimensions	Drawing archives- walk-through observations
	Suspended ceiling depth	Drawing archives- walk-through observations
	Raised floor height (if any)	Drawing archives- walk-through observations
Building fabric specification	External and internal wall build-ups	Drawing archives- walk-through observations- literature
	Roof build-up	Drawing archives- literature
	Floor build-up	Drawing archives- literature
	Windows glass and frame materials and dimensions	Drawing archives- walk-through observations- literature- interviews- elevation images
HVAC	As-built mechanical layout	Drawing archives- walk-through observations
	General HVAC configuration	Drawing archives- walk-through observations- interviews- satellite images (to detect roof top components)- elevations (to detect terminal/ zonal components)
	Cooling type(s)	Interviews- walk-through observations- drawing archives- satellite images- elevation images
	Cooling capacity	Interviews- drawing archives- walk-through observations
	Cooling operation schedule	Interviews- walk-through observations- literature
	Cooling setpoint control	Interviews- walk-through observations- literature
	Heating type(s)	Interviews- walk-through observations- drawing archives- satellite images- elevation images
	Heating capacity	Interviews- drawing archives- walk-through observations
	Heating operation schedule	Interviews- walk-through- literature
	Heating setpoint control	Interviews- walk-through- literature
	Mechanical ventilation specs	Interviews- walk-through observations- drawing archives
	Mechanical ventilation controls	Interviews- walk-through observations- drawing archives
	Heat recovery specification	Interviews- walk-through observations- drawing archives
	Economizers specification	Interviews- walk-through observations- drawing archives
	Ceiling/ wall fans use	Walk-through observations- interviews
	Window opening controls	Interviews- walk-through observations- literature
Airtightness	Data on airtightness or permeability	Literature
Occupancy	Number of occupants	Interviews- literature
	Functions of the building zones	Walk-through observations- drawing archives- interviews
	Occupancy schedules	Interviews
	Internal blinds operation	Walk-through observations- interviews
	Zones and times for occupancy overruns	Interviews
	Location and operation of server rooms	Interviews
	Periods of underoccupancy	Interviews
	Special and seasonal events that influence occupancy	Interviews- literature
	Lifts in operation	Interviews- drawing archives
Lighting	Lighting power density	Walk-through observations- luminaire inspection- interior images- drawing archives
	Illuminance levels	Measurements taken using Multi-Function Monitor device (LUTRON LM-8102) in a ten-zone sample.
	Lighting operation controls	Walk-through- interviews - interior images
	External lighting capacity and control	Interviews- night images
Plug loads	Electric equipment used	Walk-through observations- literature
	Equipment use frequency	Walk-through observations- interviews- literature
	Percentages of employees who use computers	Walk-through observations- interviews
Domestic hot water	Hot water availability, capacity, and fuel.	Walk-through observations- interviews- bills
Metered data	Electricity utility bills	Bills
	Gas utility bills	Bills
	Submeter mapping to end-uses	Bills- interviews
	Solar energy production	Bills- interviews
Miscellaneous	Information on any full or partial renovation implemented before	Interviews- walk-through observations
	Auxiliary load calculations	Interviews- walk-through observations

Table 9
ASHRAE-derived office occupancy schedule after adjustment

Days	*Hours*	*Schedule fraction (0–1)*
Typical weekday	00:00 – 06:00	0
	06:00 – 07:00	0.10
	07:00 – 08:00	0.20
	08:00 – 17:00	0.95
	17:00 – 18:00	0.30
	18:00 – 22:00	0.10
	22:00 – 24:00	0.05
Fridays	00:00 – 06:00	0
	06:00 – 18:00	0.05
	18:00 – 24:00	0
Saturdays	00:00 – 06:00	0
	06:00 – 08:00	0.10
	08:00 – 12:00	0.30

(*continued on next page*)

Table 9 (*continued*)

Days	*Hours*	*Schedule fraction (0–1)*
	12:00 – 17:00	0.10
	17:00 – 19:00	0.05
	19:00 – 24:00	0

Facility Managers (FM) Interview Forms
Pre-interview information:

1. Can you provide the architectural and/or mechanical drawing packages for the building? Are they as built drawings? Please send the available material through.
2. Can you send the monthly utility bills data (electricity, and gas if applicable) over one at least one year? Please send the data available.

General information and building occupancy:

1. What is the average number of daily occupants in the building?

- Do you have any periodical events that cause major changes in the occupancy patterns?
- What is the frequency of use of the seminar rooms? How full would the rooms be during an event?
- Are there certain spaces that are open for the public? What are they, and how many visitors would the building typically receive on a daily basis?

2. What is the typical operation schedule of the facility?

- Are there any exceptions?
- Are there any spaces that have an extended occupancy or operation schedules? Please specify.
- Are there any spaces that work less than the typical schedule? Please specify.
- Are there any night shifts? Please specify.

3. Can you provide architectural and/or mechanical drawing packages for the building? Are they as built?
4. Do utility bills show the total or the net energy consumption?

- If there are several meters installed, can you explain in more detail what the meters measure?
- Are there electric or gas water heaters installed?
- Are there any PVs or solar heaters installed?
- What is the power of the PV plant?

1. Are there any spaces with special thermal control requirements (like labs or server rooms)?

- If yes, are these spaces sub-metered?
- If they are not sub-metered, can you give more information about the power of the appliances installed in the rooms, the operation conditions, and the typical operation schedule?

Thermal comfort controls (*this is filled by the interviewer based on the FM responses*)

1. Do you have full, partial, or no control over the HVAC system installed? Please explain your scope of control.

Full control	Partial control	No control
⨂	⨂	⨂

2. Which of the following HVAC controls are deployed in the HVAC strategy to reach thermal comfort?

(*continued on next page*)

(*continued*)

	HVAC control	How?
⊗	Setpoint temperature,	
⊗	Economizer	
⊗	Night ventilation	
⊗	Humidification	
⊗	Dehumidification	
⊗	Early operation of the HVAC system	

3. Who has control on the setpoint temperatures?

The facility manager	The occupants
⊗	⊗

4. What is the typical cooling setpoint temperature in the summer?

20°C	21°C	22°C	23°C	24°C	25°C	26°C	N/A
⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗

5. What is the typical heating setpoint temperature in the winter?

18°C	19°C	20°C	21°C	22°C	23°C	24°C	N/A
⊗	⊗	⊗	⊗	⊗	⊗	⊗	⊗

6. Based on your observations, which of the following can be a typical occupants' thermal adaptation behaviour in the office spaces in the building?

(*continued on next page*)

(*continued*)

	Never	Sometimes	Always
Clothing	⊗	⊗	⊗
Windows (open/close)	⊗	⊗	⊗
HVAC (on/off)	⊗	⊗	⊗
Setpoint temperature	⊗	⊗	⊗
Fans (on/off)	⊗	⊗	⊗
Location from the window	⊗	⊗	⊗
Blinds (up/down)	⊗	⊗	⊗

Lighting

1. How will you describe the natural vs the artificial light percentages of the light mix in the office spaces?

	Natural light	Artificial light
⊗	0%	100%
⊗	25%	75%
⊗	50%	50%
⊗	75%	25%
⊗	100%	0%

2. Based on your observation, what is the typical percentage of artificial lighting usage in the office spaces (% of switched on lights) during lighting operation hours?

(*continued on next page*)

(*continued*)

25% of the lights ⊗	50% of the lights ⊗
75% of the lights ⊗	100% of the lights ⊗

3. Based on your observation, what is the typical percentage of artificial lighting usage in the access spaces (% of switched on lights) during lighting operation hours?

25% of the lights ⊗	50% of the lights ⊗
75% of the lights ⊗	100% of the lights ⊗

Policies

4. Are there any energy performance policies or targets you are required or aiming to fulfil? Could the building fulfil these targets?

Miscellaneous

5. What are the challenges that you found in the building operation?
6. Are there any building performance deficiencies that you would like to share?
7. Based on the research brief, would you like to add or suggest anything you think can be valuable to the research?

Data availability

Data will be made available on request.

References

ASHRAE. (2013). *ANSI/ASHRAE Standard 55-2013*.

ASHRAE. (2014). *ASHRAE Guideline 14-2014, Measurement of Energy, Demand, and Water Savings*.

Assaad, R., 2014. Making sense of Arab labor markets: The enduring legacy of dualism. IZA J. Labor Dev. 3 (1), 6. https://doi.org/10.1186/2193-9020-3-6.

Chae, Y., Lee, Y., Longinott, D., 2016. Assessment of Retrofitting Measures for a Large Historic Research Facility Using a Building Energy Simulation Model. Energies 9 (6), 466. https://doi.org/10.3390/en9060466.

Coakley, D., Raftery, P., Keane, M., 2014. A review of methods to match building energy simulation models to measured data. Renew. Sustain. Energy Rev. 37, 123–141. https://doi.org/10.1016/j.rser.2014.05.007.

Duarte, C., Budwig, R., Van Den Wymelenberg, K., 2015. Energy and demand implication of using recommended practice occupancy diversity factors compared to real occupancy data in whole building energy simulation. Journal of Building Performance Simulation 8 (6), 408–423. https://doi.org/10.1080/19401493.2014.966275.

Elharidi, A.M., Tuohy, P.G., Teamah, M.A., Hanafy, A.A., 2017. Energy and indoor environmental performance of typical Egyptian offices: Survey, baseline model and

uncertainties. Energy Build. 135, 367–384. https://doi.org/10.1016/j.enbuild.2016.11.011.
Elharidi, A.M., Tuohy, P.G., Teamah, M.A., 2018. The energy and indoor environmental performance of Egyptian offices: Parameter analysis and future policy. Energy Build. 158, 431–452. https://doi.org/10.1016/j.enbuild.2017.10.035.
Fabrizio, E., Monetti, V., 2015. Methodologies and Advancements in the Calibration of Building Energy Models. Energies 8 (4), 2548–2574. https://doi.org/10.3390/en8042548.
Gindling, T.H., Hasnain, Z., Newhouse, D., Shi, R., 2020. Are public sector workers in developing countries overpaid? Evidence from a new global dataset. World Dev. 126, 104737. https://doi.org/10.1016/j.worlddev.2019.104737.
Guerra-Santin, O., Boess, S., Konstantinou, T., Romero Herrera, N., Klein, T., Silvester, S., 2017. Designing for residents: Building monitoring and co-creation in social housing renovation in the Netherlands. Energy Res. Soc. Sci. 32, 164–179. https://doi.org/10.1016/j.erss.2017.03.009.
Hamada, A., Raslan, R., Mumovic, D., 2021. Cost optimal energy retrofit strategies for public administrative buildings: A Cairo case study. J. Phys. Conf. Ser. 2042 (1), 012160. https://doi.org/10.1088/1742-6596/2042/1/012160.
Hamada, A.A., Hong, S.-M., & Raslan, R. (2025). *Evaluating the Operational Performance in Cairo's Public Administrative Buildings: Stock Characterisation and Typical Energy Use*. https://doi.org/10.2139/ssrn.5129476.
Hammad, M. (1963). *Egypt is building (Arabic: مصر تبنى)*. Tarek Waly Centre Digital Archive.
Hamouda, M. (2024). *Emirati consortium wins bid to repurpose National Party HQ land in Tahrir Square: Egypt sovereign fund - Urban & Transport - Egypt*. Ahram Online. ⟨https://english.ahram.org.eg/News/515236.aspx⟩.
Hanna, G.B., 2015. Energy Conservation in Governmental and commercial Buildings in Egypt. Int. J. Mod. Energy Res. 5, 34–41.
Jain, N., Burman, E., Robertson, C., Stamp, S., Shrubsole, C., Aletta, F., Barrett, E., Oberman, T., Kang, J., Raynham, P., Mumovic, D., Davies, M., 2020. Building performance evaluation: Balancing energy and indoor environmental quality in a UK school building. Build. Serv. Eng. Res. Technol. 41 (3), 343–360. https://doi.org/10.1177/0143624419897397.
Jain, N., Burman, E., Davies, M., Davies, M., 2020. IMPROVING MODEL CALIBRATION METHODS: A CASE STUDY APPLICATION OF INCORPORATING IEQ WITH ENERGY. Build. Simul.
Jain, N., Burman, E., Stamp, S., Mumovic, D., Davies, M., 2020. Cross-sectoral assessment of the performance gap using calibrated building energy performance simulation. Energy Build. 224, 110271. https://doi.org/10.1016/j.enbuild.2020.110271.
Karaguzel, O.T., Lam, K.P., 2011. Development of whole-building energy performance models as benchmarks for retrofit projects. Proc. 2011 Winter Simul. Conf. (WSC) 838–849. https://doi.org/10.1109/wsc.2011.6147810.
Khoury, J., Alameddine, Z., Hollmuller, P., 2017. Understanding and bridging the energy performance gap in building retrofit. Energy Procedia 122, 217–222. https://doi.org/10.1016/j.egypro.2017.07.348.
Kristensen, M.H., Choudhary, R., Petersen, S., 2017. Bayesian calibration of building energy models: Comparison of predictive accuracy using metered utility data of different temporal resolution. Energy Procedia 122, 277–282. https://doi.org/10.1016/j.egypro.2017.07.322.
Leroy, L., Letellier-Duchesne, S., Kummert, M., 2019. Using Model Calibration To Improve Urban Modeling. Build. Simul. Conf. Proc. 16, 3531–3539. https://doi.org/10.26868/25222708.2019.210707.
Li, J., Iulo, L.D., Poerschke, U., 2023. A Review of the Energy Performance Gap between Predicted and Actual Use in Buildings. Build. Simul. Conf. Proc. 18. https://doi.org/10.26868/25222708.2023.1430.
Maghsoudi Nia, E., Qian, Q., Visscher, H., 2022. An Investigation of Occupants' Energy Perceptions in Energy Efficient Retrofitted Residential Buildings: A Review Paper. IOP Conference Series Earth Environmental Science 1085 (1), 012021. https://doi.org/10.1088/1755-1315/1085/1/012021.
Miller, C., Hu, H., Klesch, L., 2013. Hybrid calibration methodology for building energy models coupling sensor data and stochastic modeling. 1st IEEE Conf. Technol. Sustain. (SusTech) 2013, 37–43. https://doi.org/10.1109/sustech.2013.6617295.
Pachano, J.E., Fernández-Vigil Iglesias, M., Saiz, J.C., Fernández Bandera, C., 2023. Two-stage multi-step energy model calibration of the cooling systems of a large-space commercial building. Appl. Therm. Eng. 230, 120638. https://doi.org/10.1016/j.applthermaleng.2023.120638.
Raafat, R., Marey, A., Goubran, S., 2023. Experimental Study of Envelope Airtightness in New Egyptian Residential Dwellings. Buildings 13 (3), 728. https://doi.org/10.3390/buildings13030728.
Raftery, P., Keane, M., O'Donnell, J., 2011. Calibrating whole building energy models: An evidence-based methodology. Energy Build. 43 (9), 2356–2364. https://doi.org/10.1016/j.enbuild.2011.05.020.
Salah, F. (2023, April 17). Ministry of Interior's former headquarters repurposing project: Here's what you should know. *Dailynewsegypt.* ⟨https://www.dailynewsegypt.com/2023/04/17/ministry-of-interiors-former-headquarters-repurposing-project-heres-what-you-should-know/⟩.
Shahen, M.E., Kotani, K., Kakinaka, M., Managi, S., 2020. Wage and labor mobility between public, formal private and informal private sectors in a developing country. Econ. Anal. Policy 68, 101–113. https://doi.org/10.1016/j.eap.2020.09.006.
Shrubsole, C., Hamilton, I.G., Zimmermann, N., Papachristos, G., Broyd, T., Burman, E., Mumovic, D., Zhu, Y., Lin, B., Davies, M., 2019. Bridging the gap: The need for a systems thinking approach in understanding and addressing energy and environmental performance in buildings. Indoor Built Environ. 28 (1), 100–117. https://doi.org/10.1177/1420326X17753513.
Taheri, M., Rastogi, P., Parry, C., Wegienka, A., 2019. Benchmarking Building Energy Consumption Using Efficiency Factors. Build. Simul. Conf. Proc. 16, 3863–3870. https://doi.org/10.26868/25222708.2019.210575.
The World Bank & ESMAP. (2017). *Arab Republic of Egypt- Egypt Energy Efficiency Implementation- Energy Efficiency and Rooftop Solar PV opportunities: Report Summary* (No. ACS22504). Energy Sector Management Assessment Programme. ⟨https://documents1.worldbank.org/curated/en/578631498760292189/pdf/Final-Output-Summary.pdf⟩.
Werr, P. (2024, January). *With government relocated, Egypt set to unveil overhaul of downtown Cairo* [News]. Reuters. ⟨https://www.reuters.com/world/africa/with-government-relocated-egypt-set-unveil-overhaul-downtown-cairo-2024-01-24/⟩.
Yilmaz, I., Gunay, B., Newsham, G., & Wills, A. (2021, September 1). An inquiry into the accuracy of the energy model calibration process. *Building Simulation Conference Proceedings*. 2021 Building Simulation Conference. https://doi.org/10.26868/25222708.2021.30658.