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ORIGINAL ARTICLE

Retrofitting strategy for building envelopes to achieve energy efficiency

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KEYWORDS

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Building envelope;
Higher educational spaces;
Simulation tools;
Hot aid zones

Abstract With the excessive energy consumption worldwide, the demand for saving strategies increases. Energy consumption in public buildings increased drastically over the last decade. Significant policy actions towards the promotion of energy-efficiency in the building sector have been developed with different intensity and structure. This study aims at proposing a retrofit strategy in an attempt to improve energy efficiency in a sample of higher educational buildings located in a hot arid climate (Egypt). Retrofitting some of the building's envelope features can provide comfort without compromising functional needs. Comfort needs, which include thermal, visual and acoustical, can reduce energy consumption. Emphasis is placed on thermal comfort in terms of energy efficiency. Some of the important measures used in the retrofitting process of the building envelope include: external walls' insulation, windows' glazing type, air tightness (infiltration) and solar shading. The study results show that simple retrofit strategies such as solar shading, window glazing, air tightness then insulation can reduce energy consumption of an average of 33%. From the feasible envelope features' used in this study, the research provides a suggestion for design codes that maintains thermal comfort, propose a feasible strategy for retrofitting and a baseline reference specifically devised for local energy efficiency.

1. Introduction

Unfortunately, retrofitting of existing buildings in the third world countries focuses on structural or aesthetic measures and mainly on historical buildings for conservation. Reducing energy consumption levels is of equal importance due to its financial impact. It should not be underestimated that a building with better indoor air conditions and low fuel consumption reduces carbon dioxide emissions and pollutes less the environment [7]. Governments around the world have taken strong measures towards the retrofit of existing buildings in terms of improving energy performance. The ODYSSEE database provides a comprehensive monitoring of energy efficiency trends in all the sectors and priority areas to address EU policies [3]. In UK, part of the government strategy is to meet a target of an 80% reduction in the UK's carbon emissions by the year 2050 [18]. The European Energy Performance of Buildings Directive demands a 20% energy savings target by 2020 [2]. In the USA, the Department of Energy (DOE) which participates in both the ASHRAE (American Society of

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Heating, Refrigerating and Air-Conditioning Engineers) and ICC (Internal Codes Council) development processes, developed and submitted code change proposals that strive to make cost-effective, energy efficient upgrades to current model codes [28]. The recent publication of Standard 90.1-2016 marks the latest edition of the Standard, setting the stage for future building energy efficiency requirements in commercial buildings. The new technical envelope requirements include [1]:

- Mandatory requirements for envelope verification, supporting reduced air infiltration, and increased requirements for air leakage to overhead coiling doors.
- More stringent prescriptive requirements for metal building roofs and walls, fenestration, and opaque doors.
- Improved clarity of exterior walls definitions, building orientation, and clarity around the effective R-value of air spaces.
- New requirements based on the addition of climate zone 0.

Suggestion has been estimated that 75% of U.S. buildings will be new or renovated by 2035. Building energy codes ensure they use energy efficiently over the life of the building. A general overview can be shown in Table 1 which gives a brief summary of building envelope policy assessment of major regions. Some of the high rating regions have building envelope material test, rating and labeling assessment [19].

Currently, Housing and Building National Research Center [17] has published codes for energy efficiency in residential and commercial buildings. Air conditioning system in buildings consumed 56% of total energy consumed in buildings [24]. Energy consumption in Egyptian public buildings, including administrative, educational and health buildings (9%) is the second largest type after residential (40%) [4]. According to the International Energy Agency (IEA) in the USA which defines energy efficiency as a way of managing and restraining the growth in energy consumption a report published by IEA's EBCP states that educational buildings consume high energy and therefore their retrofit is a necessity within this sector [11]. Although it is important to state that energy consumption in educational buildings depends, mainly on the building's activities, time of use and number of students, employees and academic staff.

In most of the retrofit projects, energy efficient retrofit strategies are not applied due to a lack of knowledge about the amount of investment required and the efficiency of the potential energy saving strategies [7]. For many, it is the complexity of retrofit and financing that present a barrier to intervention and uptake [14]. Based on the correct retrofitting strategy improvement of the building envelope energy performance is provided. To understand thermal performance of retrofit the properties of the existing buildings must first be understood [13].

Most of the public buildings specifically educational in hot arid climates consume large amounts of energy. The energy usage is focused on thermal comfort. Simple feasible retrofit variables can provide thermal comfort and hence reduce this energy.

The objective of the study is to investigate experimentally a retrofitting strategy for higher educational building envelopes. This first objective is to evaluate the thermal comfort efficiency and in turn energy performance after adding some feasible retrofit features that reduces energy usage. The second objective is to provide a process for retrofit strategy in higher educational buildings that provides thermal comfort that match with functional standards. These retrofit objectives can be set as a legislative measure for energy efficient educational spaces. Nevertheless, it is essential to set energy efficient and code enforced retrofit measures to start on national levels.

This research adopts an inductive methodology, whereby it starts with a limited definition of the problem and relevant practices and as the work proceeds a clearer perspective is identified. As the research progresses into the application part the multiplicity of challenges unfolds. Specific parameters and factors are cross-examined and checked to reveal a definite course of action and required interventions. These are then taken into consideration and incorporated into a full standpoint and orientation to develop the necessary approach with viable guidelines and solutions.

This paper consists of two parts. The first part presents a theoretical discourse that reviews variables and criteria of retrofitting existing buildings' envelopes and the approaches found worldwide designated to address energy efficiency & achieving thermal comfort in higher educational spaces. This study is an attempt to test & appraise specific notions in the domain of envelope retrofit, as suggested by experiences elsewhere. The main aim is to increase general insight, and to focus more on a conceptual framework of the process.

The later part of study reviews several cases within the specific context of Egypt (defined as hot arid) in order to test the theoretical views on a pragmatic level. Such a multi-step methodology is envisaged to help in better addressing the general research problem in a local climatic context with its precise

Table 1 Building envelope policy assessment of major regions. Source: [19].

Region/Policy	Asian	Brazil	China	EU	India	Japan/Korea	Mexico	Middle East	Australia	Russia	South Africa	USA
Governance	L	M	H	H	M	M	M	L	M	L	M	M
Energy Prices	L	M	M	H	M	H	L	L	M	L	M	M
Infrastructure and human capacity	M	L	M	H	M	H	M	L	M	M	M	H
Commodity of efficient materials	L	M	H	H	M	H	M	L	M	M	L	H
Voluntary programs	L	L	L	M	L	L	L	L	L	L	L	L
Mandatory building codes	L	L	M	H	L	M	M	L	M	M	M	H

Note: H: High, M: Medium, L: Low.

conditions and particular circumstances. The empirical study (of three cases) aims to describe and examine a representative sample, what elements are shared, the relations and the mutual impacts and influences. It is conceived as a vehicle to link the ideas and propositions and to cross examine specific practices of retrofitting for building envelopes. This would be of great significance in formulating relevant guidelines and thus suggest adequate strategies for all groups involved in the architecture delivery process.

2. Retrofit strategy

A study made by Ardente et al. [5] indicated that the most significant benefits of energy consumption assessment were the improvement of envelope thermal insulations, lighting and glazing [5]. According to Joseph Rowntree Housing Trust (JRHT) thermal performance of a building relies on its ability to resist air penetration as well as its ability to prevent heat exchange through structure [21]. Fig. 1 illustrates heat flow of an un-insulated cool-climate building. In a study made by Basarir et al. [7] on energy efficient retrofit methods at the building envelopes of the school buildings it was found that if retrofit is applied, annual fuel cost would be reduced approximately one-third of the current situation of the building [7]. In a study made by Farmer et al. [16] on off-the-shelf solutions to the retrofit challenge specifically on thermal performance it was found that with suitable attention to detail to design, specification and installation, off-the-shelf thermal upgrade measures can realize the reduction in U-values anticipated and hence it can significantly reduce heat requirements for space and in term CO_2 emissions [16]. In Egypt, a study made by Attia et al. [6] addressing the impacts and potentials of community scale low-energy retrofit on a middle-income urban residential area in Cairo it was found that by envelope retrofit, efficient solar protection, high thermal inertia, and hybrid ventilation strategies; in addition to domestic water heating, photovoltaic panels and solar thermal air conditioning (A combined strategy of retrofit) achieved up to 83% total reduction in electric energy demand [6].

Erhorn-Kluttig et al. [15] on energy-efficient renovation of educational buildings, found that added insulation, low-emissivity coated windows, efficient electrical lighting systems and new heating systems can enhance energy-efficiency in educational buildings in Denmark [15]. In an attempt to evaluate the energy performance of the faculty of architecture engineering for zero energy university buildings in Tripoli Lebanon, Osama et al. [23] found that retrofitting strategies in the envelope could reduce energy up to 28% [23]. In another study made by Aboulnaga et al. [4] on sustainability of higher educational buildings specifically on a retrofitting approach to improve energy performance and mitigate CO_2 emission in hot climates, it was found that with some retrofitting approaches in glazing, insulation and green roof application could reduce 15% electrical energy consumption from the baseline energy use [4].

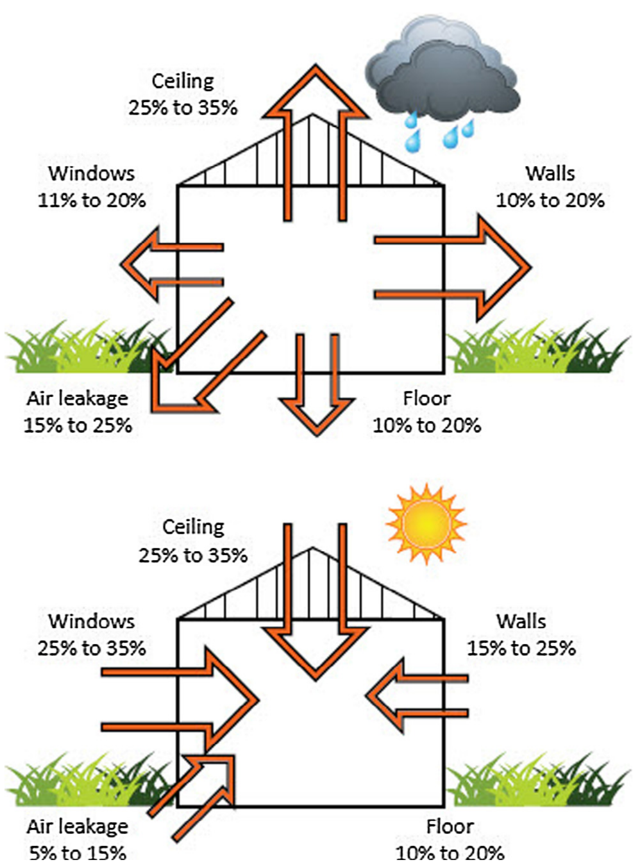

Figure 1 Heat Flow in an Un-insulated Cool-Climate House. Source: [9].

3. Envelope retrofit strategies

In general, building envelopes include the resistance to air, water, heat, light, and noise transfer. As for thermal envelopes, they include outer walls, roof, foundation, windows and doors. The purpose of the thermal envelope is to prevent heat transfer form interior of a house to its exterior in winter and vice versa in summer. For instance, windows in educational spaces should be located at the sides and if subject to solar gain should be tinted glass with a "low E" rating to reduce heat transfer [27].

Retrofit is defined as to install, fit, or adapt for use with something older. Recently, retrofitting refers to the addition of new technology or features to older systems for some reason or another. Some of reasons for retrofit could be for the improvement of power plant efficiency; for strengthening older buildings in order to make them earthquake resistant; or for the improvement of existing buildings with energy efficiency equipment [30].

Building and environmental conditions from outdoor to indoor, whose variation may influence the inter-coupled variables, are outdoor air temperature, solar radiation in environmental conditions; radiation cooling/heating and ventilation type in HVAC systems; internal heat gains and schedule of occupancy and operating conditions; wall, ceiling, floor and WWR of building envelope properties; and finally floor area and ceiling height in building size can determine the whole building thermal and indoor airflow behaviors, whereas individual characteristics may have distinctive influence [32]. Fig. 2 can show some of those variables that can affect the interior of a building.

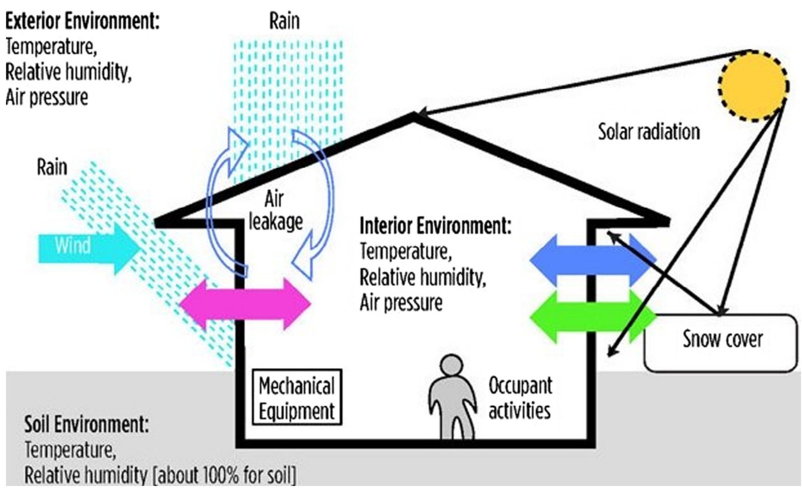

Figure 2 Building and Environmental Variables that can affect the Interior of Buildings. Source: [26].

3.1. Selected variables/criteria

From previous studies it was found that thermal comfort which plays a major role in energy consumption can be achieved by adding slight modifications to previously constructed buildings by the use of the following selected issues based on their efficiency and feasibility for retrofit:

3.1.1. Insulation and thermal bridge

High thermal mass structure such (stone, masonry, or concrete) with framing structure cavities act as thermal bridges. For that reason insulation is a necessity. A new approach to construction has been Structural Insulation Panels (SIP). SIP is a prefabricated building panel that usually includes facers, such as oriented strand board or plywood, and insulated core, such as Expanded Polystyrene System (EPS) insulation.

Extruded polystyrene has been suggested for thermal insulation on the outside of the building in hot regions [6]. Extruded polystyrene exhibits good characteristics with respect to its durability and resistance to moisture transfer. According to the HBRC [17], the thermal resistances (*R*-values) between 0.90 and 2.3 m^2 °C/W for wall and roof sections respectively are recommended. As part of the retrofit plan, edge insulation for window systems are proposed to minimize thermal bridging in the buildings of hot regions [6].

Studies have shown different types of insulation materials used for different construction parts with slightly different in *R*-values. These types include blankets (made mainly of fiberglass); concrete blocks (including foam material); foam boards (made mainly of polystyrene); insulating concrete forms (ICFs); loose-fill and blow-in (made mainly of cellulose); reflective systems such as foil; rigid fibrous or fiber insulation; sprayed cementitious foam; and structural insulated panels (SIPs). Each type is applied differently and has its own advantages according to where it is applied [12].

3.1.2. Air tightness and infiltration

Normal air movement in and out of buildings is known as air leakage. Air leakage is measured by air change per hour (AC/H). Natural weather conditions, such as temperature differences and wind can increase air leakage. Simulation on a large number of building types have shown that reducing air leakage can save 5–40% of heating and cooling energy (OECD/IEA [22]. Air leakage can be reduced by using sealants, gaskets and additional window panels.

3.1.3. Window glazing

Windows have several functions. In addition to its function as providing access to a building or space, it provides daylight, offers security and heat flow. For this reason, appropriate size, orientation and glazing is a necessity. Heat flow depends on season, building type and operation of the building. If the building is cooled and the outdoor temperature is hot, the window should retain (high *U*-values) keep out heat from the sun and enable heat to be shed from the building (low SHGC or *g*-value).

Currently single-glazed, with clear glass and poorly insulated frames are mostly used in many regions of the world. These have *U*-values of approximately 4.5 watts per square meter Kelvin (W/m^2 K) to 5.6 W/m^2 K. Most of the OECD (Organization for Economic Co-operation and Development) member countries have moved to double-glazed windows with low-e coatings, low conductive frames, and inert gas are used in the residential section that provides lower *U*-values (OECD/IEA [22]). In some climates, advanced static glazing combined with well insulated window systems and architectural shading is used to optimize seasonal impacts. Generally, a triple-glazed window system with two layers of low-e glass, high solar heat gain, low conductive frame, exterior shading in moderate European climate is used for best results.

3.1.4. Solar shading

The use of solar shading devices is an important aspect in many energy-efficient building design strategies. Some of the solar control and shading systems according to Whole Building Design Guide (2016) include: external overhangs (fins); horizontal reflecting surfaces (light shelves); low shading coefficient (SC) glass; interior glare control devices such as Venetian blinds or adjustable louvers; and landscape features such as mature trees or hedge rows [29]. It is recommended by WBDG [29], to use fixed overhangs on south-facing glass to control direct beam solar radiation. The optimal length of an

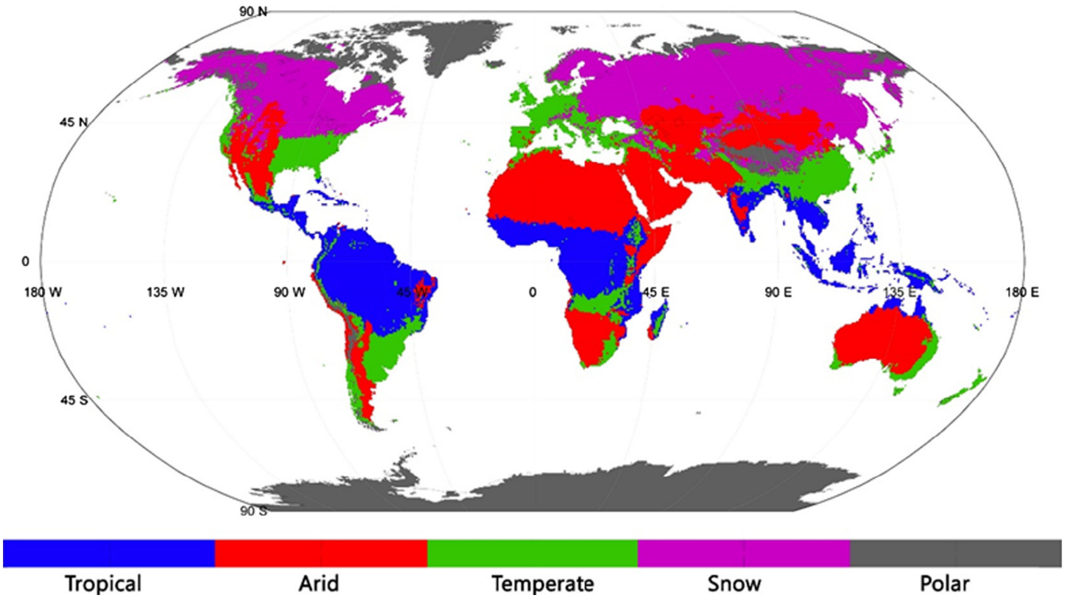

Figure 3 Koppen-Geiger Climate Classification Map. Source: [20].

Table 2 Brief description of the first building used for the study.

Location	Special Programs Building, Faculty of Engineering, Tanta University, Gharbeia Governorate.
Geographic Zone	30.0° N, 30.4° E
Climate Region	Hot Arid
Building Type(s)	Educational
Area Footprint	680 m^2
Project Scope	Classroom Sample
Completed	May 2014
Simulation Software	Design Builder via Energy Plus
Goal	Reduce Energy Consumption

overhang depends on the window size and the relative importance of heating and cooling in buildings. Minimizing east and west glass is also recommended. Although Venetian blinds or vertical louvers do not significantly reduce cooling loads yet these devices offer glare control. It is well know that, shading is not needed for the north facing facades.

Generally, shading strategies differ according to latitude, sunlight periods and building orientation. Another important matter is to consider both reducing building peak heat gain and cooling requirements as well as improve the natural lighting quality of the interiors. A wide range of adjustable shading products are available commercially from canvas awnings to solar screens, roll-down blinds, shutters, and vertical louvers.

4. Case study: Materials

4.1. Simulation tool (modeling process)

Simulation is carried out using the Design Builder graphical user interface (GUI), incorporating the Energy Plus calculation engine. Design Builder is chosen as it offers flexible geometry input and extensive material libraries and load profiles. In addition, it has control procedures, which assure accuracy of the results in comparison to stand-alone Energy Plus engine [25].

The base simulation model is created according to current construction details, materials, and systems in the case regions. The purpose of creating a base model is to estimate the annual energy consumption of conventional construction practice for the case study projects without retrofit. This way, it can be possible to compare the role and sensitivity of each individual component and system after retrofit in terms of total energy consumption.

4.2. Site description & data gathering

Three existing buildings located in hot arid regions of northern Egypt were used in the study. Fig. 3 shows Koppen-Geiger climate classification map. The first building is a five story building of a footprint 680 m^2, as can be shown in Table 2. The building is one of the Faculty of Engineering, Tanta University establishments located in Gharbeia Governorate, oriented along east-west axis with a right angle towards north. Most of the floors serve as educational spaces for special programs in Engineering as can be shown in Fig. 4.

The second building is six story building of a footprint 1800 m^2, as can be shown in Table 3. The building is one the Higher Institute for Science and Technology establishments located at Beheira Governorate, oriented along east-west axis with a right angle towards south. Most of the floors serve as

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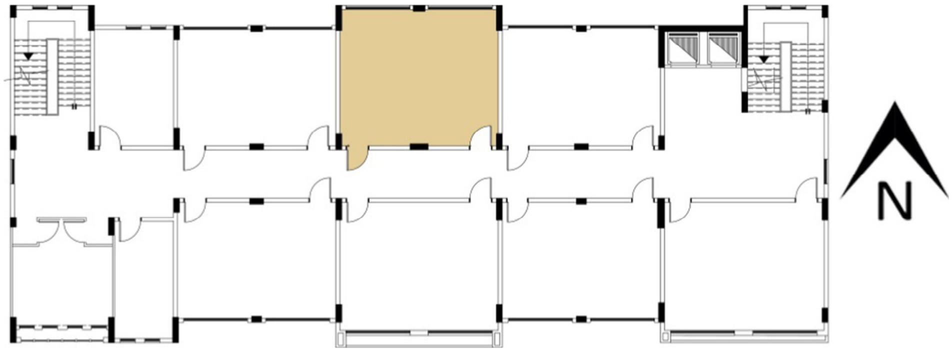

Figure 4 Standard Floor Plan Indicating the Study Area at Special Programs Building, Faculty of Engineering, Tanta University, Gharbeia Governorate.

Table 3 Brief description of the second building used for the study.

Location	Higher Institute for Science and Technology, Beheira Governorate.
Geographic Zone	30.6°N, 29.5°E
Climate Region	Hot Arid
Building Type(s)	Educational
Area Footprint	1800 m^2
Project Scope	Classroom Sample
Completed	July 2007
Simulation Software	Design Builder via Energy Plus
Goal	Reduce Energy Consumption

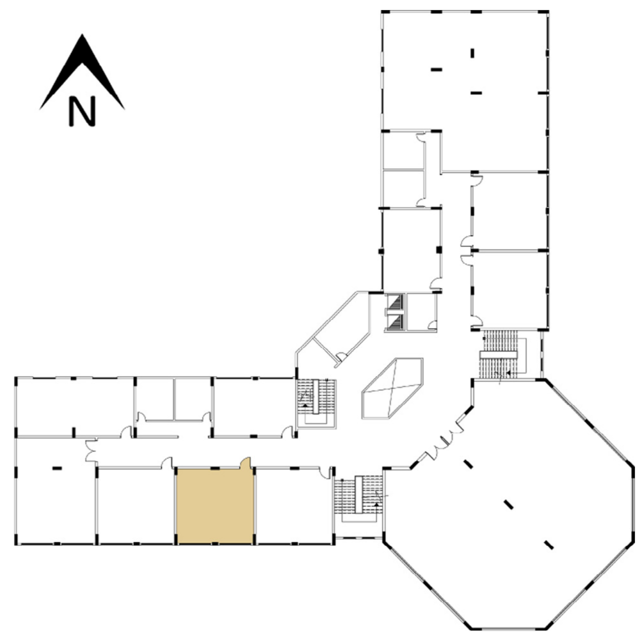

Figure 5 Standard Floor Plan Indicating the Study Area at the Higher Institute for Science and Technology, Beheira Governorate.

educational spaces for Engineering Departments as can be shown in Fig. 5.

The third building is a five story building of a footprint 1230 m^2, as can be shown in Table 4. The building is one of the Faculty of Engineering, AAST establishments located in Alexandria Governorate, oriented along east-west axis with an angle of 45° towards southwest. Most of the floors serve as educational spaces for as can be shown in Fig. 6.

The classroom/lecture rooms selected for the study were randomly chosen from the three different higher educational buildings of three different climatic zones. The three zones built within the last decade, represent standard educational spaces in Egypt, and since there are no legislative measures for these spaces selection depended on variety of orientation, size and climatic zone. Usually classroom standards are to accommodate 40–50 students. Fig. 3 shows the location of the selected classroom/lecture room within the selected educational buildings. Table 5 gives a brief description of the study areas in baseline condition.

The location of Tanta, Egypt; Alexandria, Egypt; and Beheira, Egypt (hot arid climate of northern Egypt) and the associated hourly weather data files including temperature, wind speed, solar radiation, and relative humidity has been selected in DesignBuilder for simulation.

A schedule for the occupancy of the building has also been selected with holiday schedule of educational universities in Egypt taken into consideration; all week days from 8.00 to 18.00 except Friday + 120 days for holiday. Environmental control for cooling by electricity has been identified according to CIBSE Guide B: Cooling: 19–25 °C [10]. In order to study the building operation strategies throughout the year due to seasonal variation of the baseline model, simulations were carried out for the three case studies in baseline condition of the total annual breakdowns.

4.3. Energy retrofit strategy/criteria

The target of this application is to achieve most significant, practical, retrofit strategies for energy saving. The research developed various passive and active retrofit strategies such

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Table 4 Brief description of the third building used for the study.

Location	Arab Academy for Science and Technology (AAST), Alexandria Governorate
Geographic Zone	31.2°N, 30.3°E
Climate Region	Hot Arid
Building Type(s)	Educational
Area Footprint	1230 m^2
Project Scope	Classroom Sample
Completed	January 2015
Simulation Software	Design Builder via Energy Plus
Goal	Reduce Energy Consumption

as envelope retrofit (insulation, air tightness, window glazing, and external shading), and hybrid ventilation strategies. The strategies are applied on the three samples of classroom/lecture rooms. Based on previous studies and tests the following selected strategies were chosen for the study:

4.3.1. Insulation

For insulation 0.05 m of EPS Expanded Polystyrene was added to external walls as can be shown in Fig. 7 which illustrates a section of the wall layers using EPS on the current constructed walls. EPS is an inorganic and rot-proof insulation material. EPS has become accepted world-wide as safe, highly effective, economical form of building insulation. In addition to moisture resistant, EPS insulation boards are highly energy efficient lightweight, easy to handle and a stable long-term insulation material.

4.3.2. Air tightness

Airtightness /permeability were improved from 0.7 AC/H to best practice 0.3 AC/H by sealing around windows, vents and doors. As has been previously mentioned, air leakage is measured by air change per hour (AC/H). Air tightness depends on the number and size of air leakage paths as well as the difference in air pressure between the inside and outside. Nevertheless, air tightness improves comfort, air quality, and fewer condensation problems and as a result saves energy.

4.3.3. Windows glazing

Changing the single glazed window-aluminum frame to low-e double glazed window 4/6/4 mm Argon filled. Insulating glass units may be double or triple. Although triple is better yet double is more affordable and available. Argon filling was found to be low cost, clear, non-toxic, naturally occurring gas with a lower thermal conductance than air. Although there are several types of solar control glazing: tinted (metal oxide), reflective, spectrally selective and low-e coating. Yet, low-e coated glazing was found to be clear and available for high, moderate or low solar gain [8]. In addition to energy saving, it was found to be the most suitable for different seasons and directions.

4.3.4. External shading

Generally, metal louvers which match with the materials used in buildings are preferred for usage. After several studies were made metal louvers of 0.5 m were chosen for energy efficiency. Metal louvers are cost effective, available, flexible, durable and environmentally friendly [31].

5. Case study: Process and method

In order to achieve the objective of this research, a field survey to mark a sample of three classroom/lecture room spaces in higher educational buildings located in Egypt are described and conduction. Comparison between the selected typical classroom or lecture room in base case and selected retrofit parameters for energy efficiency is then accompanied. This task is achieved by utilizing simulation of the different retrofit

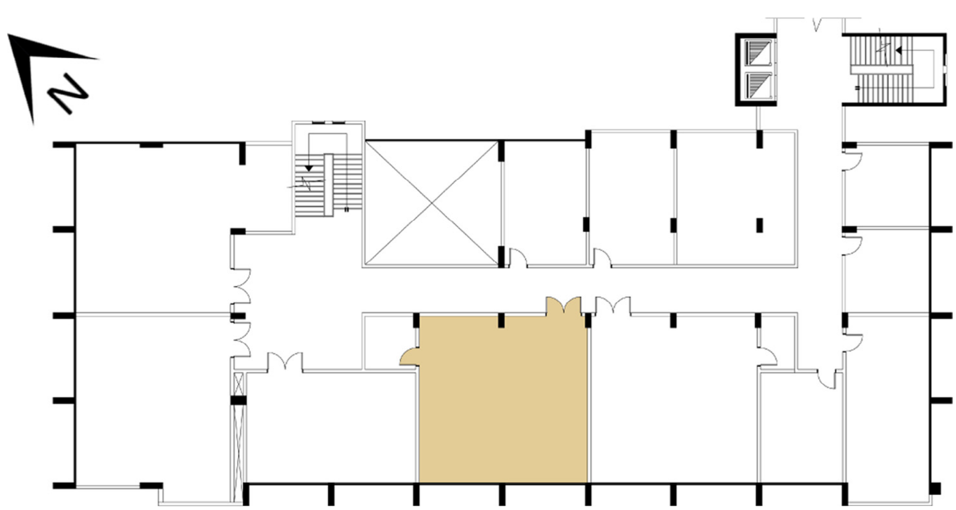
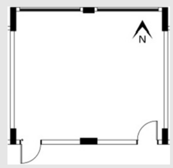
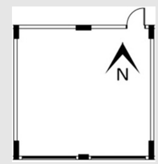
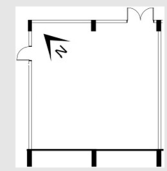


Figure 6 Standard Floor Plan Indicating the Study Area at the Arab Academy for Science and technology (AAST), Alexandria Governorate.

Table 5 Baseline condition of the selected study areas.

Classroom description		TU	BHI	AAST
Shape				
Orientation		North	South	South-West
Depth (m)		7.8	7.9	10.25
Width (m)		6.7	7.3	8.8
Height (m)		3.3	3.4	3.3
Material & Finishing	Floor	Granite Tiles	Granite Tiles	Granite Tiles
	Wall	Plaster (Dense)	Plaster (Dense)	Plaster (Dense)
	Ceiling	Rendering	Rendering	Rendering
WWR		46%	48%	55%
Window/Frame Description		Aluminum	Aluminum	Aluminum
Shading Devices		N/A	N/A	N/A
HVAC		Cooling Only	Cooling Only	Cooling Only
Lighting System		Surface Mounted (Fluorescent)	Surface Mounted (Fluorescent)	Surface Mounted (Fluorescent)
Fan Ventilation		Yes, Suspended	Yes, Suspended	Yes, Suspended
Occupation Density		0.4	0.35	0.35

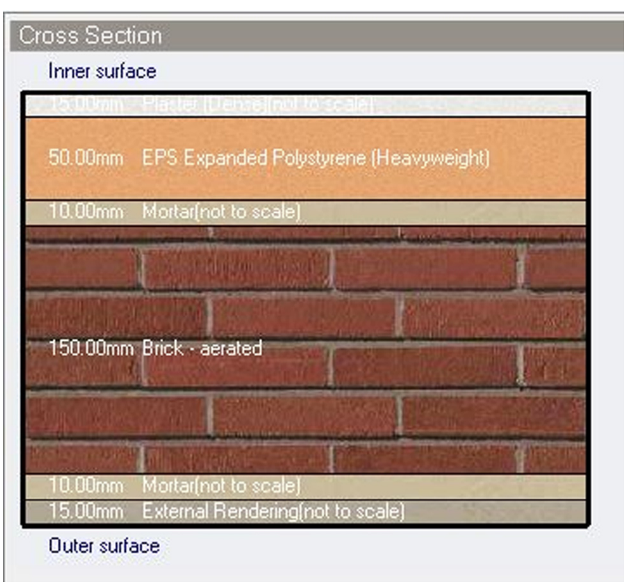


Figure 7 Section of Wall Layers Using Insulation Material on the Current Constructed Walls.

design strategies including passive and active on the selected samples.

The simulation –based methodology has the following steps:

- The location of the three sites and their associated weather data files are selected in DesignBuilder to simulate the energy performance of the each chosen buildings according to its associated climate conditions.
- A baseline case for each of the three spaces mainly depending on electric lighting and HVAC systems, 20.0 cm brick-wall construction material with no insulation, are described and their total energy consumption is calculated, followed by testing numerous retrofit variables such as glazing type, insulation, air tightness and solar shading.
- The most efficient retrofit variables are then simulated based on energy consumption and compared to the basic conventional spaces.
- From simulation results spaces are then tested in different orientation to reach a retrofit model for educational spaces that are most energy efficient.

Table 6 Energy breakdown (W h/m^2) in accordance with the different strategies.

Energy breakdown (W h/m^2)					
Retrofit strategy	Base case	Double glazing	Air tightness	External wall insulation	Solar shading
Tanta University	3843.01	3414.92	3322.88	3270.17	2876.47
BHI	6714.55	6081.63	6126.44	6164.18	3205.78
AAST	4665.96	4422.25	4321.35	4279.01	3597.61
Average Energy Consumption	5077	4640	4590	4571	3227

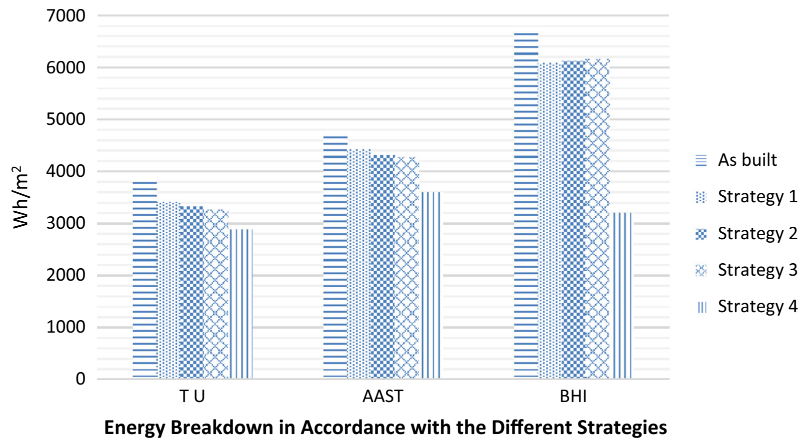


Figure 8 Energy Breakdown in Accordance with the Different Strategies.

Table 7 Reduced energy of the three case study samples.

Reduced energy (%)					
Retrofit strategy	Base case	Double glazing	Air tightness	External wall insulation	Solar shading
Tanta University	–	11%	14%	15%	25%
BHI	–	5%	7%	8%	23%
AAST	–	9%	9%	8%	52%
Achieved Reduction%	–	8%	10%	10%	33%

6. Case study: Results and discussion

6.1. Results

According to Table 6 and Fig. 8 energy consumption in the educational space sample reduced from almost 3800 W h/m^2 to almost 2900 W h/m^2 in Tanta University after retrofit by double glazing, air tightness, external wall insulation and solar shading. Energy consumption was less after retrofit measures (double glazing, air tightness, external wall insulation and solar shading) from almost 6700 W h/m^2 to 3200 W h/m^2 in BHI educational space. As for the AAST educational space it also reduced from almost 4700 W h/m^2 to almost 3200 W h/m^2 after the application of the retrofit variables (double glazing, air tightness, external wall insulation and solar shading).

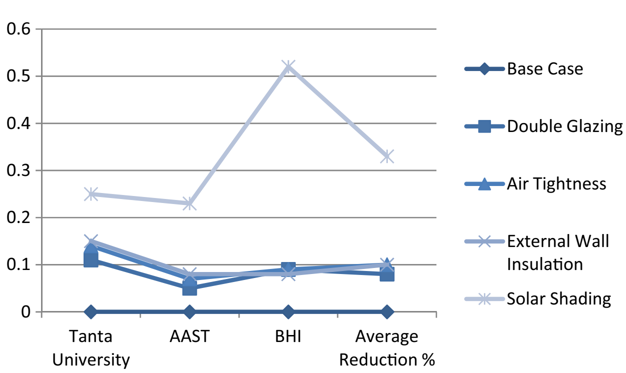


Figure 9 Reduced Amount of Energy in Accordance with Different Strategies.

6.2. Discussion

As can be seen from Table 6 and Fig. 8, the amount of energy in accordance with different strategies (W h/m^2) reduces in the three study samples with different intensity despite different location and orientation.

As can be seen from Table 7, the average classroom sample in the three educational buildings with different orientations and locations, metal louvers of 0.5 cm strategy reduced 23% of average energy consumption. Followed, was the double glazing with low-e 4/6/4 mm Argon filling strategy which reduced 8% of average energy consumption. The least effective strategy was the air tightness that reduced only 2% of average energy consumption. Insulation by adding 0.05 m of EPS Expanded Polystyrene to external walls had almost no effect on average energy consumption. A chart showing the reduced amount of energy in accordance to each strategy can be seen in Fig. 9 illustrating the importance of solar shading, followed by window glazing, then air tightness and finally insulation in the reduction of energy consumption that can reach an average of 33%.

7. Conclusion & recommendations

7.1. Conclusion

The purpose of this paper has been to present a general overview of the retrofit variables in order to examine the close relationship between the different retrofit variables and energy

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efficiency in Egypt's hot arid climate. To conclude, retrofit strategies such as solar shading can reduce energy up to 23% on average, followed is glazing strategy that reduced energy in the study sample by 8% on average. Air tightness had little effect in energy reduction on the studies samples as it reduced energy only 2% on average. Wall insulation had almost no effect as a retrofit strategy in energy reduction. In addition, it was an attempt to review the possibility of changing the priorities through simulation tests on the different design parameters that had strong impact effect on microclimate. The contents have covered retrofit enhancement methods that have strong impact on energy consumption through some of the building envelope parameters.

This research has addressed a limited scope within the quest of viable strategies to achieve the broader environmental goals. This is a dynamic domain, one that continually engenders new ideas and involves new roles on the part of different stakeholders. It is believed that new theories and approaches will emerge as the physical environments and circumstances change. The role of architects, decision makers and engineers working in the field will thus acquire further significance in the field.

7.2. Recommendations

As a broad perspective, it could be concluded that retrofit strategies affects human comfort and hence energy consumption which is a vital one, and needs to be considered/addressed through a number of recommendations, guidelines and special measures. The following is a focused set of recommendations based on the above-presented study:

- Encourage advanced building envelope retrofit technologies that can reduce cooling energy demands, although in some case it can decide cooling appliances as unnecessary.
- Enforcing the value of energy retrofits through legislative codes; and if legislation codes are difficult incentives could encourage the process.
- Thermal upgrade measures for retrofit in this study did not include environmental factors such as wind, rain, or solar radiation further studies can be made in order to enhance thermal human comfort.
- Retrofit measures can target visual comfort or other human comfort issues.
- Support research on new innovative materials and techniques that can reduce energy consumption.
- Several evaluation methodologies can be used to test these findings such as ongoing recording through monitoring, audit or questionnaires.
- Further studies can address the cost effective measures on short term and long term.
- Support other retrofit strategies in market and study their cost effect on long terms.
- More samples at different locations can verify results statistically.
- Different types of buildings can also be studied.

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