ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 51 Jan 2022, pp.105-116
Journal Homepage: erj.bu.edu.eg

Passive House (PH) Standards for Achieving Energy-efficient Office Buildings in Egypt

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Abstract; Office buildings in Egypt require expensive cooling systems, which leads to significant increase in energy consumption in summer. Rising energy prices led to the need for turning to performance assessment tools to evaluate and improve buildings energy performance. There are various world-known rating systems such as Passive House (PH), LEED and BREEAM. While, this research focuses on PH standards considered nowadays to be the most rigorous voluntary energy-based standards in building. This research aims at investigating applicability and effectiveness of using PH standards to achieve energy-efficient performance and improve thermal comfort of office buildings in Egypt. Likewise, energy performance in three office buildings in Egypt was analyzed by e-QUEST simulation. One of the buildings is a new office building in CFC, the second is AEC office building, and the last building is Egypt Tours Tower. New planned office buildings in this research have been designed using PH standards and principles, as well, cost would be looked at to determine whether PH criteria is viable in Egypt. Evaluation of new proposed buildings was done by PH standards. However, final conclusions were that PH standards can be used to achieve energy-efficient performance of medium-rise office buildings in Egypt.

Keywords: Passive House (PH) standards, building energy-efficiency performance, numerical simulation results.

Acronyms

- GB: Green Building
- HRV: Heat Recovery Ventilation
- PE: Primary Energy
- PH: Passive House
- PHI: Passive House Institute
- PHPP: Passive House Planning Package
- PU: Polyurethane Foam
- e-QUEST: Quick Energy Simulation Tool
- XPS: Extruded Polystyrene

Introduction

Egypt is facing significant challenges in office buildings' energy consumption. It was found that these buildings consume 40% of total energy thereto in air and water treatment, lighting 37%, office equipment 12%, while remaining 11% is used in construction and manufacture of building materials. [4]

However, office buildings require expensive cooling systems, which leads to significant increase in energy consumption in summer. Rising energy prices led to the need for turning to performance assessment tools and green building (GB) rating systems to address energy challenges in Egypt and to evaluate and improve buildings energy performance. There are various world-known GB certification systems and rating tools using performance-based criteria such as Passive House (PH), LEED and BREEAM. [12, 13]

While, this research focuses on PH standards considered nowadays to be the most rigorous voluntary energy-based standards in design and construction industry. [8]

PH standards was promoted as an energy-efficient solution to high-electricity bills, as well, it is characterized by special high thermal comfort. PH standards is easier to explain, despite its features are not easily displayed, furthermore. PH standards is either achieved or not achieved in building. [9]

PH ''Passivhaus'' in German, is the first developed program in Germany, and quickly spread out to become a voluntary standard in other parts of the world.PH is not only one of world's leading energy-efficiency standards but also a sustainable environment-friendly construction concept providing comfortable, affordable, ecological and high-quality buildings at the same time. Thorough scientific investigation was carried out on hundreds of PH buildings projects, proving that PH buildings allow for heating and cooling related energy savings of up to 90% compared with typical building stock, and over 75% compared with average new builds. Similar energy savings were demonstrated in warm climates where buildings require more energy for cooling than for heating. [3, 5]

Cairo city is selected as the research area for modeling new threeoffice buildings by using PH standards, as well, detailed simulation-based energy performance of this proposed buildings has been analyzed. Therefore, the aim of this paper is to focus on PH standards overall benefits and whether it is viable in Egyptian building code, in immediate or distant future.

Research Problem

In Egypt, office buildings require expensive cooling systems, as well as lighting for workplaces, which leads to significant increase in energy consumption. PH buildings offer cost-effective solution for economical building with high level of indoor comfort, and low power consumption. Therefore, there is a need to investigate how it was implemented in Europe and other countries with similar climate conditions, thus comparing these with how it could be implemented in construction sector in Egypt.

Analytical studies were conducted on office buildings in Cairo, Egypt to investigate how could PH building certification criteria be met in projects to support existence of research problem, absence of performance assessment and prevailing GB rating tools in Egypt. Furthermore, this paper addresses the following questions: what are the energy cost savings in each of three cases studies? as well, which case study offered most cost-effectiveness? and are the proposed PH techniques financially viable? Likewise, it indicated that there is an urgent need for government participation in the process of implementing PH buildings in Egypt.

Research Objectives

The end of this paper is to aim at investigating effectiveness of using PH standards to achieve energy-efficient performance and improve thermal comfort of office buildings in Egypt. In order to achieve the paper main goal, the following objectives are fulfilled:

1. Examining the origin and significance of PH building;
2. Investigating how PH buildings are implemented in Europe and other countries with similar climate conditions, thus comparing these with how PH standards could be implemented in Egypt's office buildings;
3. Analyzing case studies to investigate how could PH certification criteria be met in office buildings in Cairo, Egypt; and

4. Exploring applicability and effectiveness of using PH standards for achieving energy-efficient performance and improving thermal comfort of office buildings in Egypt, as well whether the proposed PH techniques financially are viable.

Research Methodology

Energy performance in three office buildings in Cairo, Egypt was analyzed by e-QUEST simulation. Office buildings in this case study were designed and planned according to the five key design principles of PH building to evaluate building performance and improve buildings' thermal comfort including:

1. Continuous thermal insulation throughout the entire building envelope without any thermal bridging such as extruded polystyrene (XPS) insulation with thermal conductivity of 0.035 W/mK for foundation system and polyurethane (PU) foam with 0.030 W/mK for walls and roof;
2. High-performance windows and triple glazing with U_w-value of 0.80 W/m^{2}K and can achieve U-value of 0.85 W/m^{2}K for installation within the walls;
3. Airtightness and uncontrolled air leakage through gaps must be smaller than 0.6 of total building volumes per hour during a pressure test at 50Pa;
4. Building thermal bridge-free; and
5. Fresh air with heat recovery ventilation (HRV), allowing for good indoor air quality and energy saving. [2, 3, 10]

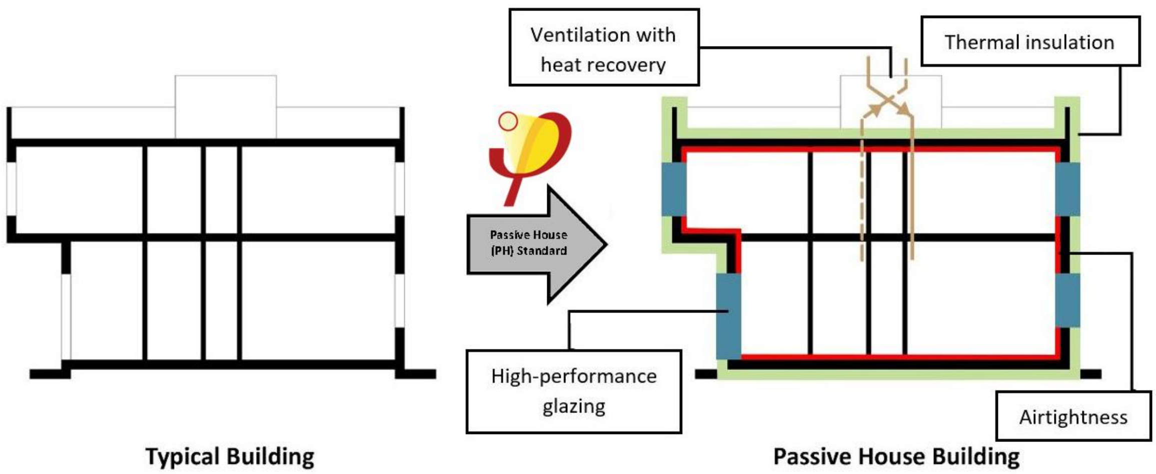


Fig.1 shows conceptual drawing for building design development using PH principles. Author (2021)

Although, office buildings in Egypt are just as models of research proposals, information of these pilot projects failed to be verified by Passive House Planning Package (PHPP) software, as there was insufficient time to contact and deal with PH certifier, thus, required procedures were not completed to obtain the PH building certification .PHPP is a well-organized energy-efficiency planning tool to calculate the building's energy balance and annual demands which whether a proposed building achieves the energy standards defined by the Passive House Institute (PHI) is verified using PHPP calculation. [1, 6]

There are several software packages for energy simulation in buildings, similar to PHPP, used to reach final results such as Energy Plus, HAP, IESVE, e-QUEST, and TRNSYS .Therefore, evaluation of new proposed buildings was done by PH standards using e-QUEST, which was used for calculating energy consumption and evaluating performance of proposed office buildings in Egypt.e-QUEST simulation requires collected data based-on basic building uses and characteristics to calculate energy performance in buildings, as well as, it is used to calculate annual heating or cooling demands and total energy use intensity.

Table (1) shows checklists for e-QUEST simulation software testing process with the whole project data, its main and alternate schedules as mentioned below.

Table (1) eQUEST Checklists					
General project information		Daylight zoning and activity areas allocation		Chilled and hot water systems control	
Building footprint		HVAC system fans equipment		Energy-efficiency measure	
Building envelope and interior constructions		HVAC system definitions and zones for temperatures and air flows		Water-source heat pump and DWH equipment	
Exterior windows, doors and shades		Heating and cooling primary equipment		Construction costs	

Finally, research steps can be concluded in Figure (2) below.

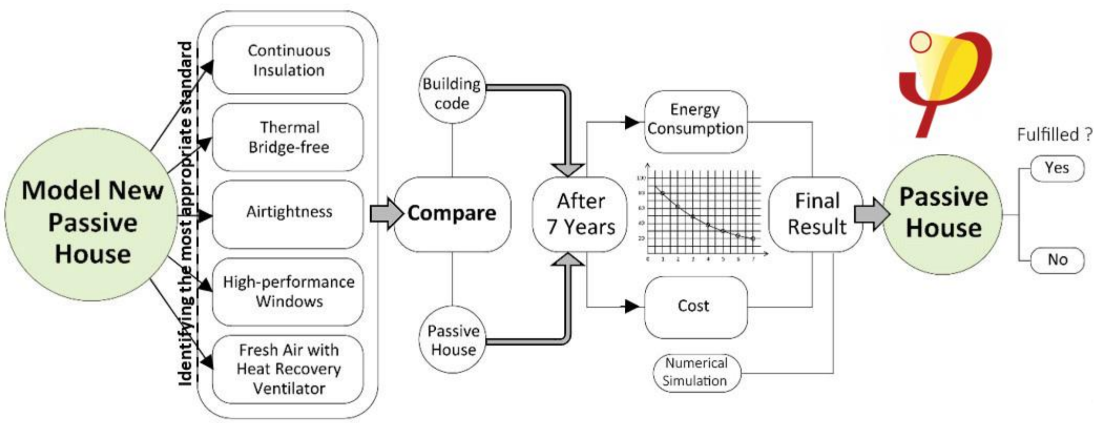


Fig.2 shows flow chart of research steps used to achieve final results. Author (2021)

Case Study

New planned design for three office buildings as illustrated in Table (2) are the pilot projects to develop new solutions in sustainable energy; these will be designed and tested according to PH standards, and whether it is viable in these buildings. When buildings fulfill and apply PH standards according to a set of key principles including HRV efficiency, well-insulated building and envelope air tightness, building occupants will enjoy a variety of benefits, including lower operating costs, improved health, comfort and reduced risk.

Table (2) shows summary database for three office buildings in Egypt.[Author, 2021]

Table (2) Office Buildings Projects Database

Project information	Office building in Cairo Festival City (CFC)	Al-Arabi Engineering Consultants (AEC) office building	Misr Travel tower
View			
Construction type	Mixed construction (masonry and steel)	Masonry construction	Masonry construction
Location	Southbound Business Park area of Cairo Festival City (CFC), New Cairo	Extension of Ramses Street, beginning of Nasr City, in front of Police College	El-Abbaseyah Square, next to the bank of Alexandria in Cairo
Floors no.	4-floors + one-floor under ground	10-floors	18-floors
Total gross floor area	6,648 m^2	9,450 m^2	33,744 m^2
Building form-factor (A/V) ratio	0.32m^{-1}	0.26 m^{-1}	0.24m^{-1}
U-value for floor slab	1.351 W/m^{2}K	1.384W/m^{2}K	1.343W/m^{2}K
U-value for external wall	2.253 W/m^{2}K	2.327W/m^{2}K	2.327W/m^{2}K
U-value for roof	0.521W/m^{2}K	0.690W/m^{2}K	0.574 W/m^{2}K
Space cooling demand	24.80 kWh/m^{2}yr.	27.02 kWh/m^{2}yr.	32.23 kWh/m^{2}yr.
Primary energy (PE) demand	131.32 kWh/m^{2}yr.	129.89 kWh/m^{2}yr.	140.55 kWh/m^{2}yr.

According to PH criteria, cooling demand should not to exceed 15 kWh/m^2/yr. annually with an additional, climate-dependent allowance for dehumidification, as well, primary energy (PE) demand should not to exceed 120 kWh/m^2/yr. annually for all applications including heating, cooling, hot water and electrical devices. [9]

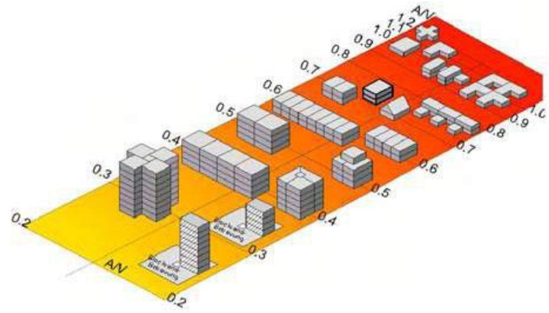
Table (3) shows building certification criteria as a PH building, it needs to meet the performance-based criteria as followed below. [6, 9]

Table (3) PH Building Performance

Space heating demand	$\leq$ 15 kWh/m^2/yr.		
Or specific heating load	$\leq$ 10 W/m^2		
Space cooling + dehumidification demand	$\leq$ 15 kWh/m^2/yr. + dehumidification contribution		
Or specific cooling load	$\leq$ 10 W/m^2		
Renewable Primary Energy (PER)	PH Classes [kWh/m^2/yr.]		
	Classic	Plus	Premium
PER demand	$\leq$ 60	$\leq$ 45	$\leq$ 30
Renewable energy generation	-	$\geq$ 60	$\geq$ 120
Non-renewable Primary Energy (PE) demand	$\leq$ 120 kWh/m^2/yr.		
Airtightness (pressurization test result n_{50})	$\leq$ 0.6 h^{-1}		

Additionally, according to PH building form and size testing, compactness of a building is indicated by the surface area to volume (A/V) ratio known as a building form-factor, that describes the relationship between building external surface area and internal surface area. This ratio has a considerable influence on energy demand, and size of a building influences the building form-factor ratio. [10, 11]

Small buildings with identical form have higher building form-factor ratios than large buildings and a favorable A/V ratio is considered to be one was $\leq 0.7\ m^{-1}$. However, the better ratio is the more economical solution, and appropriate A/V ratio is $\leq 0.3\ m^{-1}$.[5, 10]



PH building.Rob McLeod, Kym Mead (2014)

First project is an office building in Cairo Festival City (CFC), is 4-story and one-floor underground. Building houses office rooms, conference rooms and open office halls, while services are at building central core. New planned building structure consists of the following construction systems (masonry structure for full building up to third-floor ceiling; steel framed structure for exterior walls at fourth-floor; well-insulated floor slab on grade; certified PH curtain wall facades; and insulated sandwich panel roofing).

Building façade elements are mostly mounted granite stone cladding and curtain walls. Lower floor slab was 3mm epoxy thick paint finish with 60mm lightweight screed; air tightness was provided by 10mm cement render coat-plaster and 250mm XPS load bearing insulation to base of masonry. As well, 4mm waterproof layer, 150mm reinforced concrete, 100mm gravel and stone base.

External walls were 30mm granite stone cladding with aluminum c-channel and support brackets for installation externally, 15mm Gypsum board, 150mm PU foam insulation, 200mm masonry construction was provided in building. Air tightness was provided by polyethylene tape to internal block work and 15mm gypsum board internally.

While at the fourth floor, external walls were 30mm aluminum panel externally, 15 mm gypsum board, 150mm PU foam insulation, 275mm steel construction was provided in building. Air tightness was provided by polyethylene tape to internal block work and 15mm gypsum board internally.

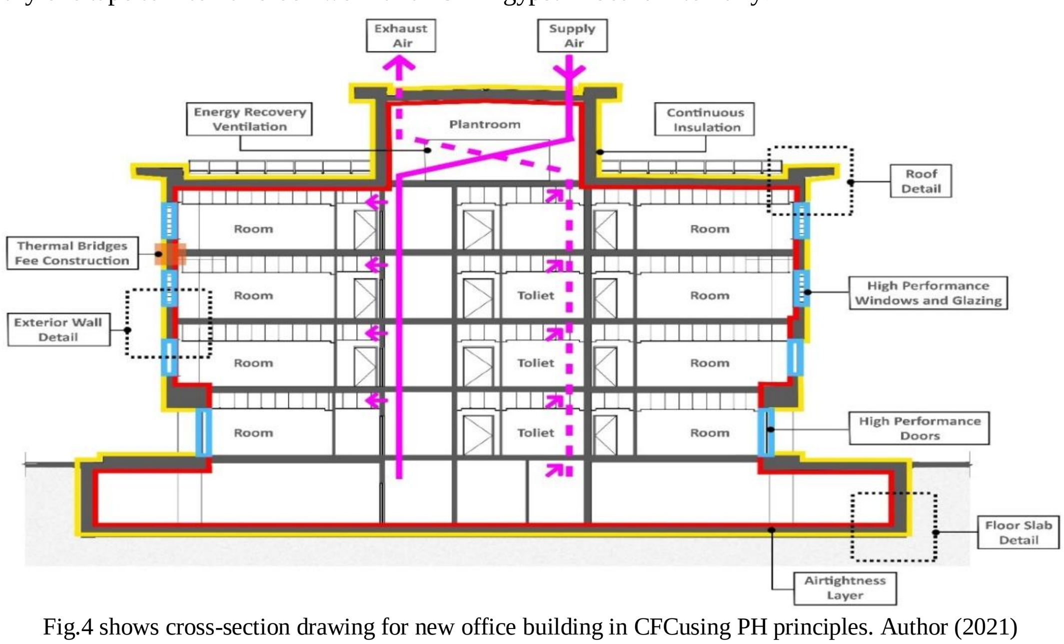


Fig.4 shows cross-section drawing for new office building in CFCusing PH principles. Author (2021)

Second project is Al-Arabi Engineering Consultants (AEC) office building, consists of two rectangular blocks, with one floor high bank between the two blocks. One of the office buildings, is 10-story with 37.5m height, while the other building consists of 7-story with 25m height. Building houses office rooms, meeting rooms, as well, representatives and heads of sectors rooms, while electricity rooms are outside around the building. New planned building structure consists of the following construction systems (masonry structure; well-insulated floor slab on grade; certified PH curtain walls and windows).Building façades elements are mostly white paint finishes, while, main façade is wholly glazed.

And finally, the last project is Misr Travel tower,is 18-story with 67m height. The tower comprises two parts; one for management company of Egypt for travel and hotels, the other part for headquarters of the ministry of tourism to manage companies and everything related to the ministry.New planned tower structure consists of the following construction systems (masonry structure; well-insulated floor slab on grade; certified PH windows). Full tower façades elements are mostly beige paint finishes.

In the second and third projects, lower floor slab has same layers including20mm thick. tiles with 60mm lightweight screed; airtightness was provided by 10mm gypsum backings coat-plaster and 250mm XPS insulation. As well, 4mm waterproof layer, 150mm reinforced concrete, 100mm gravel and stone base.

External walls in these two projectswere coat-paint finishes with 100mm concrete externally, 150mm PU foam insulation, 200mm masonry structural construction. Airtightness by polyethylene tape and 15mm gypsum board internally.

In the three projects, building top has same layers including, 20mm floor tiles, 50mm clean sand, protection board, 50mm thermal insulation, 30mm cement screed, 4mm waterproof layer, 150mm PU foam insulation, 100mm lightweight concrete, 150mm reinforced concrete, polyethylene tape and 7mm gypsum board.

According to PH component database for selecting high-performance curtain walls, windows and HRV system.

Aluminum schücocuratin wall system with U_{CW}-value of 0.79 W/m^{2}Kand $U_{CW,\ installed}$-value of 0.85 W/m^{2}K for installation were checked for first and second projects.Schüco, certified PH triple-glazed curtain walls with argon filling featuring spacer high thermal values. While in second and third projects, certified PH windows and triple glazed PVC aluminum with U_W-value of 0.80 W/m^{2}K and $U_{W,\ installed}$-value of 0.89 W/m^{2}K was checked for facades.[9]

Entrance glazed doors for three projects are same construction as curtain walls.

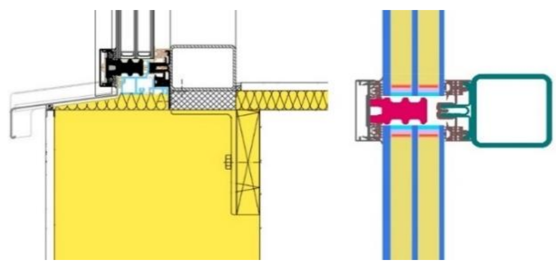


Fig.5 shows illustrative curtain wall detail installed within middle of exterior walls. PH Database (2020)Fig.3 shows the best A/V ratio for

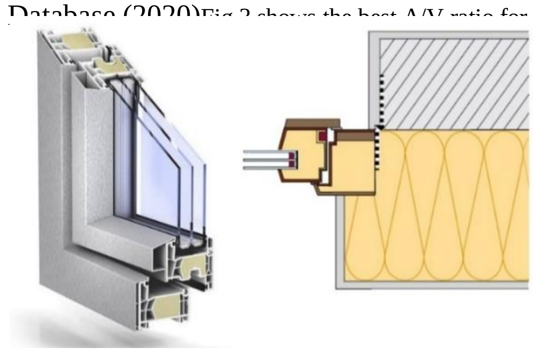


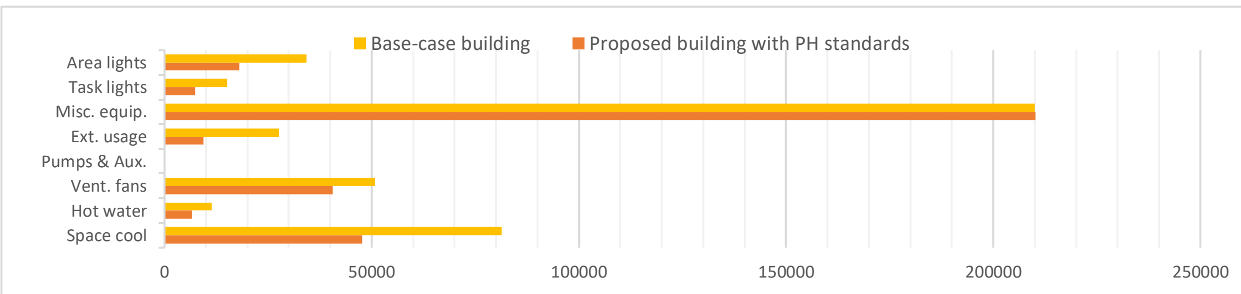
Fig.6 shows cross-section of PH window with triple-glazing.Giorgia Tzar (2018)

PH standards requires HRV to be at least 75% effective. Therefore, according to categories outlined in PH building components database for HRV systems DUPLEX 650 - 3600 Flexi, with heat recovery exchanger of efficiency up to 89% and highly efficient fans, is selected for first and third projects, while Novus 450 ventilation unit, air handling units with HRV units were used, with 89% recovery efficiency is selected for second project. Units of these systems are supplied in a versatile version allowing for both floor-standing and below ceiling installations. [1, 9]

Certified PH components such as windows, curtain walls and ventilation systems will be imported from Europe for there are no local manufacturers in Egypt, which increases as well costs of transportation and shipping process. However, high electrical energy prices can be overcome by energy conserving buildings and use of modern energy-saving technology such as Apple Mac Book Pro laptop with average power consumption of maximum 20W. [7]

Results and analysis

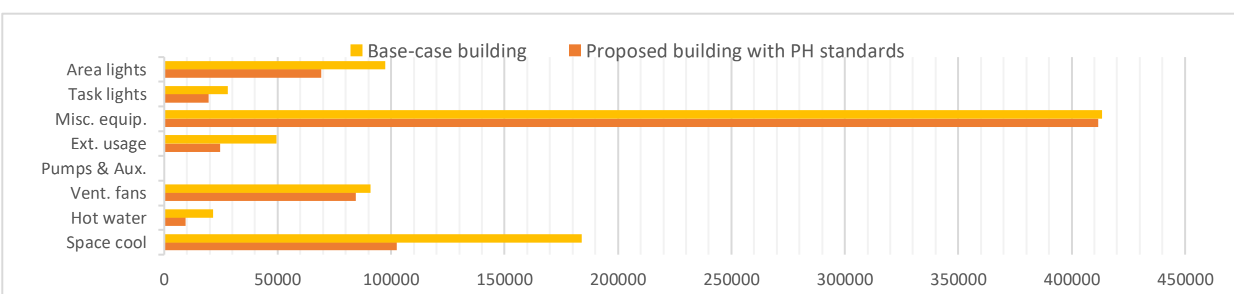
Energy use simulation readings for three projects were illustrated in Figures (7,8 and 9).This clarification represents the difference of energy performance in the buildings. Energy uses by HVAC systems, lighting and other equipment using electricity have been focused. According to e-QUEST simulation, it was found that 21% reduction of the total energy used in new planned design for office building in CFC by PH standards as shown in Figure (7), as well, it was found that 18.5% reduction of the total energy used in new planned design for AEC office building as shown in Figure (8), and it was found that 19.5% reduction of the total energy used in new planned design for Miser Travel tower as shown in Figure (9).



Energy Consumption(kWh)

Electric (kWh)	Base-case Building (kWh)	Proposed Building with PH Standards(kWh)
Space Cooling	81401.586	47639.668
Water Heating	11369.637	6597.743
Ventilation Fans	50838.539	40567.742
Pumps & Auxiliary Heat	197.4	197.25
Exterior Usage	27599.051	9383.66
Miscellaneous Equipment	210038.25	210143.609
Task Lighting	15092.09	7419.101
Area Lighting	34190.77	18115.193
Total	**430727.5**	**340063.781**

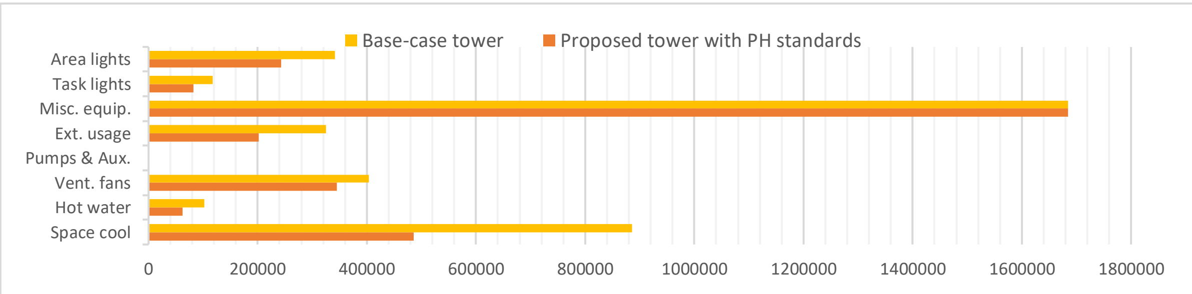
Fig.7 shows the comparison for energy consumption of office building in CFC between base-case building and proposed building with PH standards. Author (2021)



Energy Consumption(kWh)

Electric (kWh)	Base-case Building (kWh)	Proposed Building with PH Standards (kWh)
Space Cooling	184126.703	102552.555
Water Heating	21387.035	9433.481
Ventilation Fans	91016.141	84358.938
Pumps & Auxiliary Heat	148.05	148.05
Exterior Usage	49492.477	24645.59
Miscellaneous Equipment	413373.313	411691.5
Task Lighting	27985.191	19590.74
Area Lighting	97302.383	69066.25
Total	**884831.313**	**721486.813**

Fig.8 shows the comparison for energy consumption of AEC office building between base-case building and proposed building with PH standards, Author (2021)



Energy Consumption(kWh)

Electric (kWh)	Base-case Tower (kWh)	Proposed Tower with PH Standards (kWh)
Space Cooling	885547.938	485830.313
Water Heating	102031.117	62254.492
Ventilation Fans	403930	345175.594
Pumps & Auxiliary Heat	148.05	148.05
Exterior Usage	324953.563	201695.656
Miscellaneous Equipment	1685101.375	1685101.375
Task Lighting	117215.484	82390.492
Area Lighting	341711.375	243541.125
Total	**3860639**	**3106136.5**

Fig.9 shows the comparison for energy consumption of Misr Travel tower between base-case tower and new proposed tower with PH standards.Author (2021)

Limits of thermal heat transfer coefficient (U-values) into building’s context according to the PH standards are ≤ 0.15 W/m²K for walls, floors and roofs. As a rule of thumb, the lower the thermal heat transfer coefficient value, the better, for value conducts less heat energy.[31]

Table (4) shows building envelope ofU-values calculations comparison for three buildings between base-case building and proposed building using PH standards.

Project Data	Office Building in CFC		AEC Office Building		Misr Travel tower	
U-value for buildingenvelope (W/m^2K)	**Base-case building**	**Proposed building with PH standards**	**Base-case building**	**Proposed building with PH standards**	**Base-case tower**	**Proposed tower with PH standards**
Floor slab	1.351	0.157	1.384	0.158	1.343	0.159
External wall	2.253	0.141	2.327	0.127	2.327	0.127
Roof	0.521	0.116	0.690	0.117	0.574	0.114

Results show that increasing the thickness of insulation and installing HRV system reduces peak cooling demand in conditioned spaces by 38–45%.After analyzing case studies using PH standards, the cooling demand was reduced in the first project of 14.52 kWh/m^2 yr. and second project of 15.05 kWh/m^2 yr., while in the third project, it was reduced of 19.85kWh/m^2 yr. which is not achieving with PH standards. However, the PE demand was reduced in the three projects and the results are not exceed 120 kWh/m^2yr.which are achieving with PH standards. For example, it was reduced in the first project of 103.68kWh/m^2 yr., second project of 105.89 kWh/m^2 yr. and third project of 113.08 kWh/m^2 yr .Therefore, the application of HRV system for well-insulated buildings is an effective technique and minimum cost to achieve energy-efficient and improve thermal comfort of buildings.

New planned office buildings using PH standards have several custom features, which by themselves make the building a little bit more expensive than a similar sized building to be built by code. For example,resultswere summarized that the initial cost has increased by 30% in CFC office building, 38% in AEC office building and 50% in Misr Travel tower due to additional spending areas, including:

- Additional insulation in substructure and exterior walls;
- Improved U-value and reduced thermal bridges for building envelope;
- Additional works for airtightness testing of openings and doors;
- Services related to heat recovery and efficiency requirements; and
- Additional supervision for daily quality assurance.

Furthermore, these costs will be compensated and energy-costs will be saved through 5 years in the first project, and 7 years in second project, while in thirdproject, it will compensate through 8 years, however, it is not allowed for the investment which is not successful after 7 years.

Table (5)shows e-QUEST results summary for cost calculations of three proposed buildings in Egypt.[Author, 2021]

Construction Cost	CFC Office Building (EGP)	AEC Office Building (EGP)	Misr Travel tower (EGP)
Additional cost related to PH cost of total Project costs	62,168,014	166,267,957	834,134,067
	30%	38%	50%
Actual average total monthly electrical cost	73,570.8	145,997.75	386,442.5
Actual average total annual electrical cost	882,850	1,751,973	4,637,310
Monthly cost of energy	1,179,166.6	2,214,007	9,298,131.25
Total annual energy consumption cost	14,150,000	26,568,086	111,577,575
Annual electrical consumption savings	13,267,150	24,816,113	106,940,265
ROI for PH components costs of total project costs	62,168,014 / 13,267,150 = 5 years	166,267,957 / 24,816,113 = 7 years	834,134,067 / 106,940,265 = 8 years

The taller the building is, the higher construction costs will be saved slower, as in new planned Misr Travel tower, while the shorter building will save the costs faster, as in CFC office building .Therefore, medium-rise buildings with A/V ratio ranging between (0.3 - 0.7) m^{-1} using PH techniques is suitable for implementation in Egypt.

Conclusions and recommendations for future work

Energy performance for three office buildingsin this paper were analyzedwith PH standards using eQUEST simulation. After collecting data, applying new standards and analyzing the assessment tool; hence, research covered its objectives. Research key conclusions are outlined as follows:

1. Challenges to performance assessment and GB rating tools development in Egyptian construction industry are mainly that new difficult standards are dismayed and resisted due to resistance change, high initial cost, PH building construction difficulty, skilled labor shortage, and lack of knowledge about PH standards and requirements in Egyptian firms and manufacturers.
2. Research showed that PH standardsachievement has new developments and many benefits for building principles and techniques that positively impact Egyptian construction industry.
3. As well, it showed that PH standards is viable in Egypt for medium-rise buildings with A/V ratio ranging between (0.3 - 0.7) m^{-1}.
4. Final simulation showed significant reduction in energy use in three buildings and showed that the initial cost has increased by 30% in first building and this cost will compensate through 5 years, and it has increased by 38% in second building and it will compensate through 7 years, while it has increased by 50% in tower and it will compensate through 8 years, however, it is not allowed for the investment which is not successful after 7 years. The taller the building is, the higher construction costs will be saved slower, as in proposed tower, while the shorter building will save the costs faster, as in CFC office building.

Grounds for analyzing the three office buildings are based on the fact that there is a big difference in energy consumption and there are few good developments that could adopt improving energy performance and conservation in buildings.This means that installed systems in new planned buildings are more energy-efficient, as well consume minimal energy compared to base-case buildings.

However, in this paper basedon case studies, few necessary actions were recommended by the study to be considered by the Egyptian authorities, filed experts at renewable energy authority, manufacturers and faculty for implementing PH buildings in Egypt are mentioned as follows:

1. Set broad goals for PH buildings implementation in cooperation with manufacturers and set a time frame for reaching these goals.
2. Inform top management on PH building benefits and techniques through achieving PH standards and its ability to achieve energy-efficient performance and improve of buildings in Egypt on the long run.
3. Encourage staff employees to train and participate in PH certifier’s courses and PH building exam successfully passed.
4. Use PHPP applications in universities and engineering courses to train students and engineers on using energy simulation to evaluate building's performance using PH standards and to measure energy-used in buildings.
5. Collaboration and communication between engineering sectors and stakeholders should take place through shared projects.
6. Engage in partnerships with international organizations such as PHI that support buildings as accredited building certifier.

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