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Optimizing Phase Change Material on Opaque Building Envelope to Reach nZEB

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Abstract Designing a net Zero Energy Building nZEB envelope with high thermal comfort and low energy consumption is vital nowadays. There is some established specialized software for building optimization design, but these programs are time-consuming, expensive, and demand many data input of building parameters. Therefore, it is difficult to follow the optimization procedure. The aim of this research is to present a novel study to optimize the use of Phase Change Material PCM on opaque building envelope using a multi-objective optimization tool. Python (3) is employed to implement EnergyPlus to minimize the initial cost of PCM in commercial buildings, running cost and Thermal Comfort. Phase change material is a self-interactive material that respond exceptionally in different context; therefore, it is required to simulate and optimize the PCM behavior in building envelopes to determine the most effective way to use it. This research suggests a novel multi-objective optimization based on greedy algorithm, for the usage of PCM in opaque building envelopes. The objective of the proposed methodology is to identify the best Thermal comfort and optimal energy consumption by the selection of the efficient type of PCM (melting point and thickness) and the corresponding allocation of PCM material on the opaque building envelope, taking into consideration the initial and running cost. The tested model showed the best 2 locations for using PCM in Cairo is the innermost layer and inner side of airgap. The model also showed good results using PCM and Thermal comfort is enhanced using thicker layer of PCM, while conventional building materials was not able to reach minimum thermal comfort levels. After utilizing the PCM on the opaque building envelope to achieve net Zero Energy Building, a MatLab code is created to optimize the use of a photovoltaic (PV) system for renewable energy on a commercial building. It optimizes the PV efficiency of energy.

Keywords Design Builder Energy Simulation, Optimization, Phase Change Material, nZEB

1. Introduction

The key to green architecture is creating building envelope combinations that provide excellent thermal comfort while consuming little energy [1]. The thermal comfort inside the building is influenced by several factors. To improve thermal comfort for occupants and use less energy, it is crucial to consider all factors and optimize them [1]. Building performance can be increased by using the multi-objective optimization strategy. Recent years have seen significant developments in the multi-objective building performance optimization (BPO) design technique [2]. According to Attia et al. [4], 93% of research on building energy optimization (BEO) used multi-objective optimization (MOO) in early stage. Notably, accurate dynamic energy simulation software, such as EnergyPlus, TRNSYS®, or IDA ICE, is necessary for a building's proper design [5].

The building envelope plays a big part in how well energy management is carried out. There will be more energy cycles as a building's surface area increases. A major element of the technology to consider is the building envelope [5]. Building envelopes have been significantly impacted by modern technology, which has significant effect on energy use, comfort of users, and environmental considerations [7]. Buildings account for 40% of global energy use, with heating and cooling accounting for up to 60% of that [8]. The heat gains and/or losses in buildings are mostly determined by the building envelop [9]. As a result, buildings offer a significant chance to reduce high energy usage by implementing more promising alternatives, such as passive design methods, through their envelope. New studies point out the importance of different design inputs that needs to be optimized to reach a nZEB.

A single objective method is used in more than 60% of optimization studies. That means in an optimization run, a single objective can be optimized [10]. The challenges that might have an impact on the degree, to which the various parties involved in construction project design perform, are not generally recognised [11], such as minimum energy use vs. best thermal comfort, minimal energy use vs. least amount of money spent on building, and furthermore. Multi-objective optimisation is therefore frequently more applicable than single-objective optimization[12]. Previous researchers have examined the use of PCM in buildings. The performance of PCM is directly related to its use, which is the main problem that must be addressed in using PCM in the building envelope [13].

Throughout the year, PCM performance should be optimized taking into account both heating and cooling loads[14]. Multi-objective optimisation challenges arise and the set of optimal compromise solutions must be discovered using an effective and comprehensive search technique in order to enable the decision maker, the designer, to make the best choices [15].

Previous work on PCM:

The appropriate PCM melting temperature is highly related to the input processing parameters, indicating that a greater PCM melting temperature is required for a building exposed to high temperature. Additionally, the Li and Mingli studies show that PCM with a melting point inside the occupant thermal comfort zone can more successfully prolong indoor thermal comfort duration for "moderate" climate loading situations[16]. The results for Saffari M. demonstrate that the optimal melting temperature of the PCM is significantly influenced by climatic data. The optimal PCM temperature is normally between 20 and 26 ℃ in situations where heating prevails [17]. PCM temperature should be selected according to the climatic[17].

The PCM selection depends on climatic zone. In general, it can be said that the benefits of PCMs are greater in warm climates when taking into account the climatic zones[19]. The thermophysical characteristics and climatic conditions have a significant impact on PCM efficacy [20]. The optimum position of PCM should be chosen according to the climatic conditions and intended applications [21].

PCM allocation in the building envelope has different impact on the building performance. Kośny, Jan found that the internal allocation of PCM in the building surfaces like walls, ceilings, or floors were the ideal places for PCM[22]. Ayoub Gounni and Mustapha El Alami discovered that placing the PCM layer close to the heat source causes a 2 ℃ decrease in surface temperature, whereas placing it farther from the heat source has no effect[23]. The beneficial effects of PCM, which are integrated into the inside surface of the envelope, vary logarithmically with the thickness of the boards, which is one of the clearest results.[19].

The most effective thickness of PCM is from 2-4 cm thickness, embedded in the innermost layers [20].

While Carlucci approved the evaluation of layers up to 5 cm, increasing board thickness is especially advantageous: however, additional increases result in gradually lower improvements [19].

Many researchers have examined the PCM's selection. Most of them, however, simply looked at one or two components of the optimization problem[24].

The research main objective is to simulate a nZeb building envelope using PCM in Egypt. The available software does not optimize the "allocation" of materials in building envelope. Therefore, a multi- objective optimization algorithm will be developed to explore the optimum use of PCM in building envelope design using with respect to thermal comfort, running cost and initial cost on a medium office building in Cairo. Design inputs of interest include type of PCM material, thickness of PCM, Allocation of PCM in the opaque building envelope. The Office building is simulated with Design Builder as a first step, then used in the proposed new objective optimization tool generated by Python (3). After that a MATLAB code is used for the same building to produce energy and reach nZEB.

Most of earlier research, different factors affect the performance of PCM in buildings, because PCM is considered an active material. Previous studies analyze material thickness, melting point, and material allocation,

The contributions of the proposed research work area are as follows:

- A multi-objective function optimization problem has been proposed to achieve higher thermal comfort levels, minimum operational and running cost.
- Optimized solution for a medium office building model (Design Builder) using Phase Change Material on opaque office building envelope in Egypt.

- An optimized code using MATLAB is conducted to optimize the energy needed for the building after design optimization using PV on the building envelope to reach net Zero Energy Building.

The conclusion of the above contribution concludes the proposed work.

2. Methods

The research methodology based on a systematic review used the most relevant keywords to the topic (i.e., nZEB, phase change material, Building Envelope, Thermal Energy Storage, Optimization, multi-objective function). Articles were selected based on their year of publications starting from the 21st century to nowadays. Eligible articles were identified through title, abstract and findings screening. A total of 44 articles were comprehensively reviewed for inclusion. The inclusion criteria include the application of PCM on building envelope in hot climates, enhancing the thermal comfort and decreasing the total energy consumed. Benefits of using multi-objective function on building optimization. The relevant data was summarized and analyzed to the simulation using Design Builder. These data are extracted from Design builder to introduce a new methodology for multi-objective function to optimize the use of PCM in the opaque building envelope using Python (3). The methodology for the tool relies on incremental experimentation, which involves changing one aspect at a time. A MatLab code is generated for optimizing the use of photovoltaic (PV) system on the commercial building to reach nZEB. It optimizes the PV efficiency of energy. Figure 1 shows the research methodology flow chart of the current research.

3. Materials and Façade Application

PCM in particular, are practical passive technologies that can be used into building fabric to improve heat exchange and energy efficiency while decreasing energy consumption [25]. They can store a lot of thermal energy with minor temperature swing [26].

In order to lower the energy consumption in buildings, energy-efficient components with the ability to intelligently regulate room temperature are widely valued after. By utilising their thermal, optical, and mechanical capabilities throughout phase transitions, phase change materials (PCMs) have been extensively researched in recent years for intelligent temperature regulation. PCMs have huge latent heats that can delay the heat transferred to the building [27].

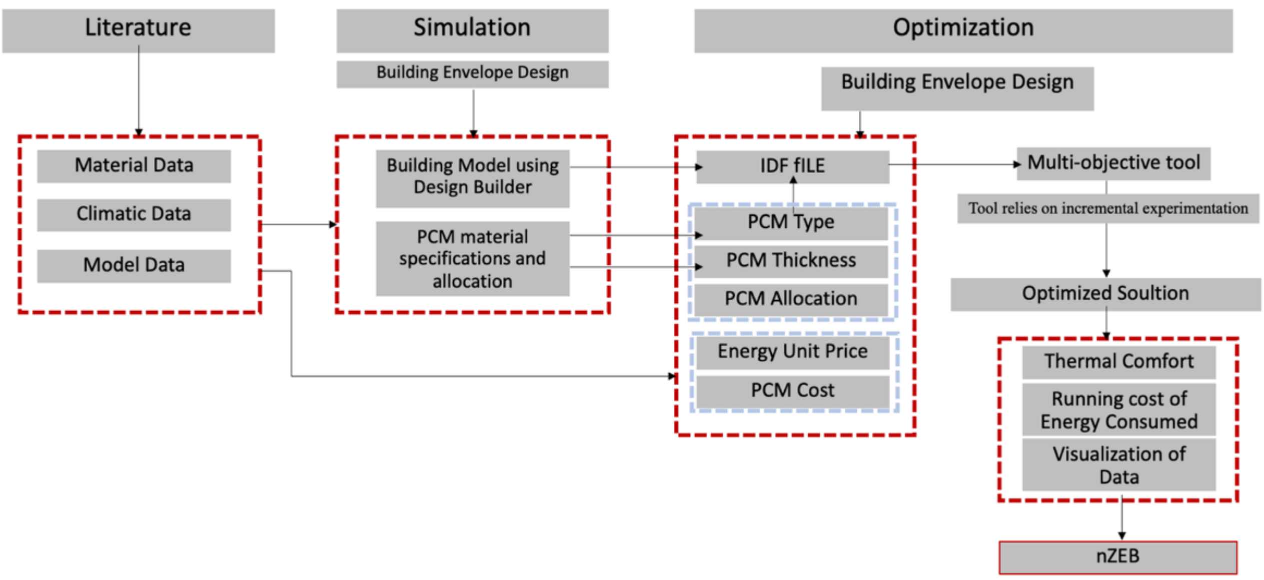


Figure 1. Research flow chart

3.1. PCM in Hot Climate Building Envelope

PCMs have been found in over 200 compositions, including chemical and inorganic compounds, eutectics, and other mixtures. In order to classify the chemicals used for thermal energy storage [28]. As illustrated in Figure 2, the basic three types of PCMs used in building wall applications are categorised based on their chemical composition. Figure 3, shows the use of various types of PCMs in various places around the world. The PCM type selection depends on the melting point which changes when the climatic conditions are changed. PCM can be used in a variety of ways, including direct inclusion, immersion, shape-stabilization, and encapsulation. Even if there are some limitations, it has some generalization. PCM can be incorporated into construction materials and elements in a variety of ways, including direct inclusion, immersion, shape-stabilization, and encapsulation[29]. Accordingly, Egypt has a tropical desert climate, therefore organic PCM might perform better there.

PCM has a considerable impact on structures in both hot and cold climates. Before deciding on a building material, take into account the surrounding environment. In contrast to inorganic materials, which have a relatively high melting point and are used in the industrial sector, PCM organic materials are often used in buildings. Due to their excellent chemical and thermal stability, high heat of fusion, and widespread availability within the required temperature range, they are frequently used to control the internal thermal climate of buildings [29].

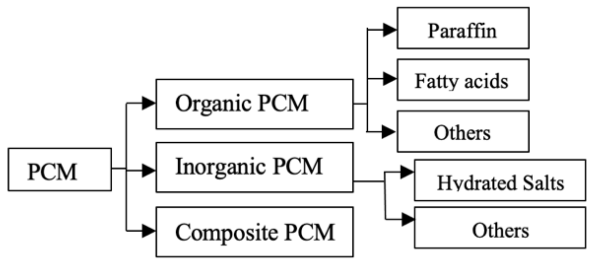


Figure 2. Classification of PCM [10]

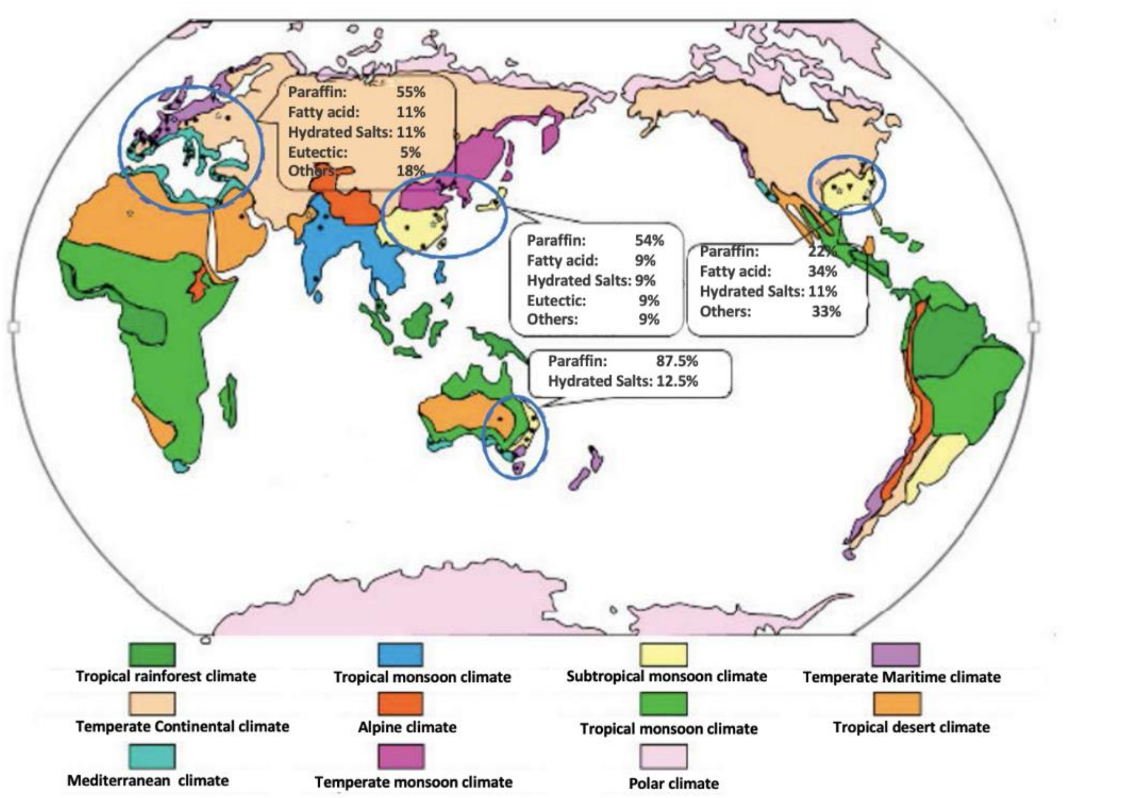


Figure 3. The use frequency of different types of PCMs indifferent areas worldwide [10]

3.2. Layering PCM

The use of PCM in the outer building envelope layers is a solution that is gaining attraction. Jin et al.'s experimental work in 2013 was one of the first efforts made to determine the best location of the PCM layer in an exterior construction wall [31]. Macro-encapsulated PCM might be located in three places in walls, according to prior studies: the inner section, the outer part, and the middle. More than 28 percent of energy was saved by carefully inserting a PCM layer between the outer side of the brick and the plaster layer in the exterior wall. Computational tools were used in the other parametric analysis of PCM placement [32]. The PCM reduces the indoor wall temperature and the potential for heat loss through walls [33]. The best PCM locations were revealed to be very sensitive on performing a daily complete melting/freezing cycle to be ready for the next day.

The application target, the PCM melting temperature, the amount of PCM, the thermal properties of the wall's materials, mechanical heating/cooling, and the orientation of the wall are all factors that can influence this. Therefore, it is recommended to use an optimization tool for testing [34].

3.3. Type of PCM

PCMs are a type of smart material that reacts to changes in temperature in its environment. As a result, in hot weather, they gather and store a lot of energy, which they then release by melting at a certain temperature. Because of their functionality, they are widely utilised in the temperature adjustment of indoor environments in buildings. As a result, selecting the melting point and thickness of the material is crucial. PCM uses two key material attributes in the design builder: Q, which is the melting point, and M, which is the material thickness. The melting temperatures of the five Q values (Q21, Q23, Q25, Q27, and Q29) are given by their values (e.g., Q21 melted at 21 ℃) [35]. To use PCM in building envelope it is recommended to simulate the material on building envelope to determine the type of material in hot climates.

4. Model Design

For simulation, an ASHRAE standard for medium commercial buildings is used to create a medium office building model. Because the structure will be in Cairo, the materials and their qualities will be determined by the Egyptian Energy Code. Design Builder simulation software is used to create the model as shown in Figure 4. As in preliminary stage, the model is built and changed in Design Builder to assess model sensitivity to material. Other considerations such as PCM type, allocation, envelope vents, initial cost, and operational cost are considered in the simulation.

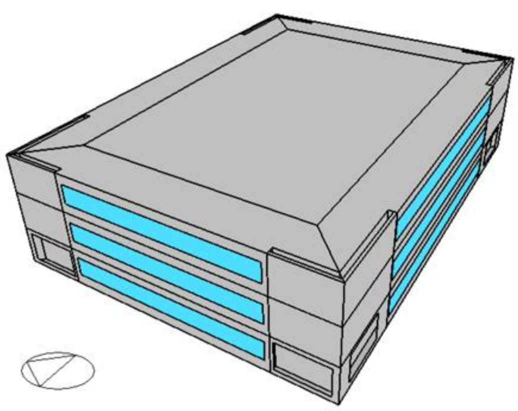


Figure 4. Building model with lower vents

The design builder model is good as a start point for the optimization design process, as the model is sensitive to the PCM as a material. HVAC and the unmet hours were reduced after adding the PCM. Also, the allocation of PCM and the air gap showed a direct impact on the building energy consumption. The simulation selected the least Thermal comfort hours with slight energy change. The results for all expected possibilities cannot be expected on a theoretical base, as the PCM is a material that has different melting point and enthalpy during the day, due to the nature of the material. This makes the model ready to run with a new optimized methodology to test different inputs and optimize the Thermal comfort, energy consumed and initial cost.

5. Optimization

To build a building using PCM material in building envelope there are several aspects need to be considered as the PCM type and PCM allocation, as these inputs affect the HVAC consumption in buildings, building comfort through the unmet hours, the initial and running cost. To consider several inputs and outputs it is essential to use an optimization tool to help reach group of optimum solutions.

Greedy algorithms are a common technique for building solutions to combinatorial optimization problems from the ground up, step by step. They can be utilised as stand-alone algorithms or as subordinate algorithmic components in more complex metaheuristics. At each building stage, the solution component to be added to the current partial solution is determined deterministically using a so-called greedy function, which is critical to the algorithm's performance. It measures the local improvement obtained by adding the corresponding component to the incumbent partial solution to evaluate each solution component [36].

Multi-objective optimization issues can be solved using a variety of ways. A set of nondominated solutions is the result of a multiple goal optimization. The Pareto set can sometimes contain a significant number of solutions (thousands in some cases). Consideration of all nondominated possibilities can be prohibitive and wasteful from the decision-perspective. Non-numerical ranking optimality analysis is the process of selecting solutions from the Pareto [36].

5.1. Simulation Tool Setup

Python 3 simulation program used libraries to run. It used the IDF files extracted from the design builder as an input and the parallel coordinate plot as a visualization tool for output. Parsing the IDF file is used through GitHub. The parallel coordinate plot visualized through Plotly.

The simulation tool uses the IDF files extracted from design builder then the tool creates different combinations and runs energy plus on them, moving to calculation of output variables from the ESO files.

The tool is designed to the user to give several inputs and simulate to come out with several outputs as seen in Figure 5.

The simulation tool is designed for the user to set group of **inputs:**

- Weather Data (.epw format):The user will choose the weather data according to the location of Building.
- 4 IDF files: The target from this file is to put the PCM layer in different building envelope allocations (e.g.: innermost- outermost – inside the air gap…etc.) The tool will include the PCM material allocation in the optimization process.
- PCM material cost

The user will be asked to put the cost for each PCM material included in Egyptian pound/m^3.

- Unit price of energy KW: As energy price varies the user can insert the unit price in KW of energy according to the current price.
- PCM total area used in the building.: The total area of PCM is defined to help the tool define the cost according to the thickness.

Expected outputs:

- Initial Cost of PCM material in Egyptian Pound: Area of PCM x Price of PCM
- Running cost of Energy consumed in KW: sum of Heating and cooling energy in KW.
- Thermal comfort in hours: The total unmet hours are defined from the simulation.
- Visualized parallel coordinate plot for all executed designs with their outputs: the tool generates a parallel plot coordinate for all executed designs with their outputs.

5.2. Simulation Run Setup.

The PCM Optimization Tool is designed to use IDF files extracted from energy plus. The tool uses IDF Version 9.1. The tool methodology is based on incremental experimentation by changing one factor at time. First the user opens a terminal and uses the path of the located code on the computer. As soon as the PCM Optimization tool program is opened a window appears as shown in Figure 6. This window will allow user to locate the file (ne file to be generated by the PCM Optimization tool), initiate the file name, select the 4 IDF files, the weather data file, the recent price of electricity in KW and the total PCM volume used.

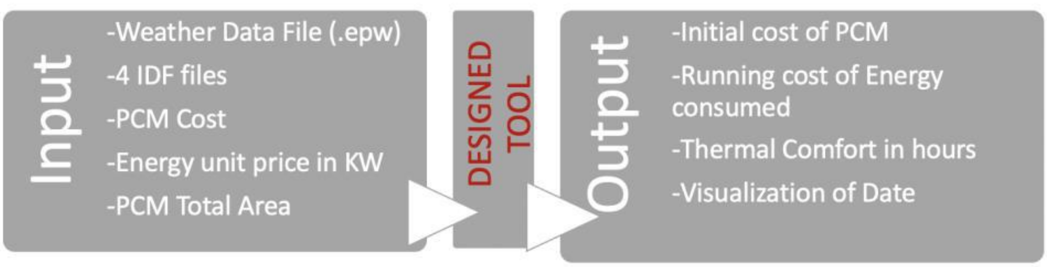


Figure 5. Tool Design (Input & Output)

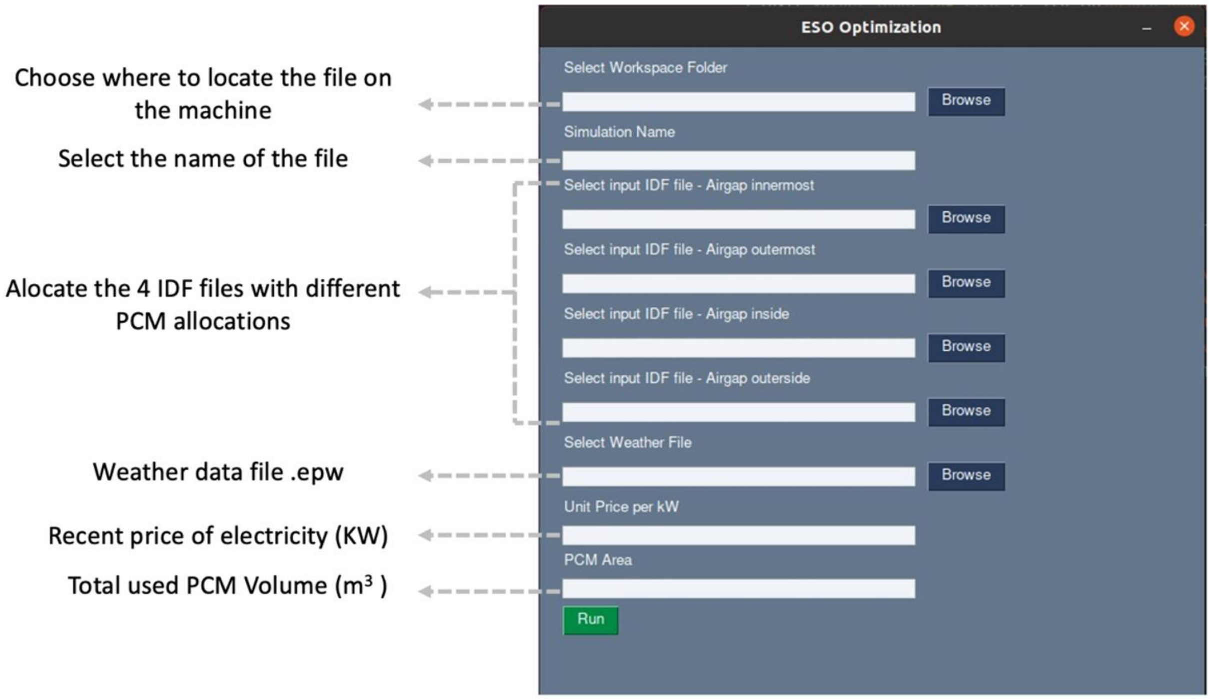


Figure 6. PCM Optimization tool program window

5.2.1. Stage 1: PCM Optimization Tool - IDF generation

This stage depends on the produced IDF. The Design Builder first extract an IDF, then this IDF runs on Energy plus to produce the version 9.1 IDF. This IDF is used by the tool to read the number of inputs (PCM material, PCM thickness, Output variables and COP). Figure 7 shows stage 1, the IDF generation flow of inputs to reach a new IDF generation. This stage takes 5 seconds on normal machine to run.

5.2.2. Stage 2: PCM Optimization Tool Simulation and Optimization

The PCM Optimization Tool uses the generated IDF file to make 5 main runs as shown in Figure 9. The tool uses the base case model, which the user selects on the first window that appears in Figure 7.

The tool uses a **multi-objective function,** which are:

- UMLH (<300 hr)
- Energy consumption (low HVAC heating and cooling)
- Initial cost (low PCM cost according to thickness of material used)

The first IDF "PCM innermost" is the base case for the user simulation. The tool first run simulates the PCM 5 different materials. The tool selects 2 optimum solutions based on the multi objective function. Second, the tool selects 2 optimum solutions from the 5 PCM materials and runs 4 different PCM thickness. The tool selects the best 2 solutions based on the multi objective function. Third, the tool takes 4 optimum solutions from the 4 different PCM thickness and simulates 4 different PCM allocations in the building envelope (PCM allocation is shown in Table 1). Finally, the tool comes up with 8 optimized solutions, estimated time for stage 2 on standard machine is 14 (Total number of variables)* 15 mins = 210 minutes. The PCM Optimization tool simulation sequence for a group of design solutions are not all viable solutions have been identified.

5.2.3. Stage 3: PCM Optimization Tool – Visualization

The PCM Optimization Tool uses the optimized PCM case from stage 2 and generates a table and Parallel coordinate plot for the user. The tool produces 4 tables and 4 Parallel coordinate plots. It produces 2 for each part of simulation and a grouped one for final visualization. This means one for type of PCM, one for PCM thickness, one for PCM allocation and all the above in one chart. This will help the user to compare and visualize all data easily. The table and parallel coordinate plot display all data input and output as shown in Figure 8.

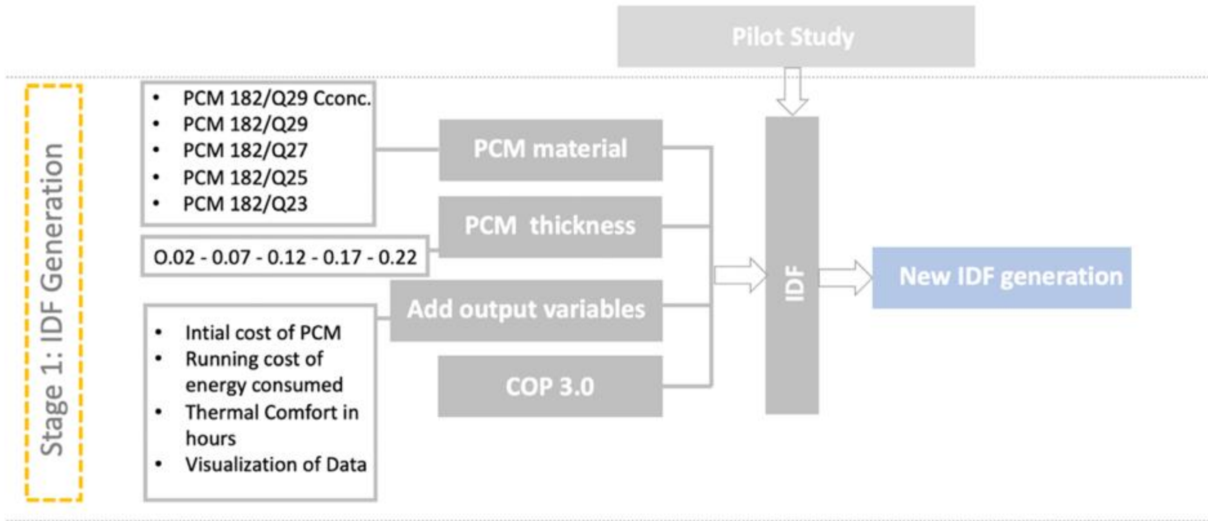
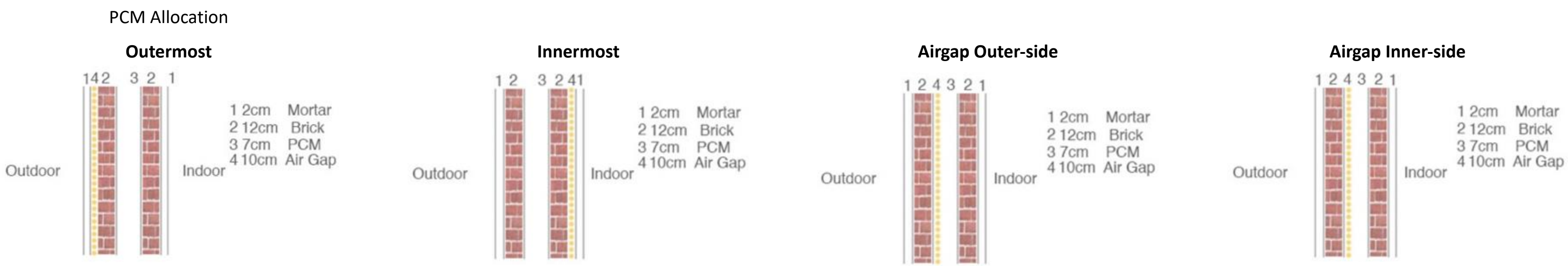


Figure 7. PCM Optimization Tool stage 1: IDF generation

Table 1. PCM allocation in the opaque building envelope



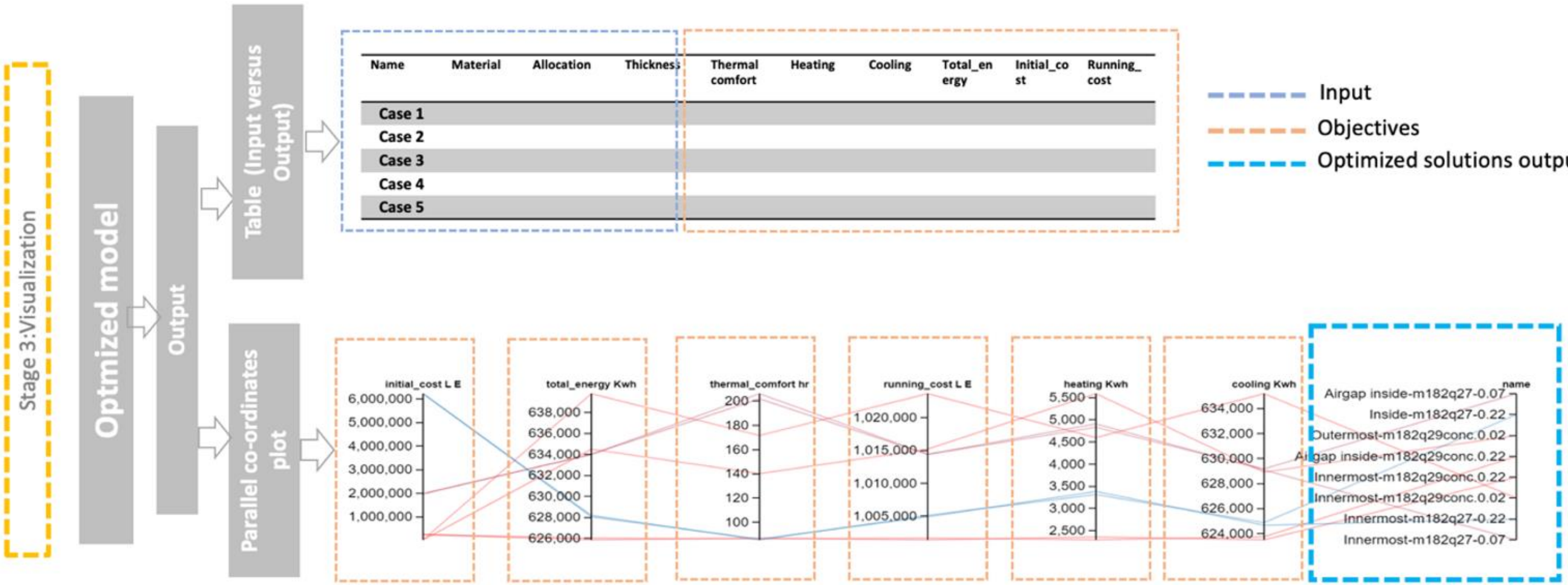


Figure 8. PCM Optimization Tool – Visualization

5.3. Model Using PCM Optimization Tool

In this section PCM Optimization Tool use the IDF generated from to test the model envelope. The following data will be used as the input data in the first window that appears to the tool to complete stage 1:

- Price for energy in commercial buildings in Egypt 2021 is 1.60 L.E for Kw/h.
- Table 2 shows PCM material properties
- Table 3 shows PCM material price

Table 2. PCM properties

Type of PCM	Conductivity (W/m-K)	Specific Heat (J/Kg-K)	Density (Kg/m^3)
BioPCM® M182/Q29 Concentrated	0.1600	2500.00	850
BioPCM® M182/Q29	0.2000	1970.00	235.00
BioPCM® M182/Q27			
BioPCM® M182/Q25			

Table 3. PCM price according to thickness

Bio PCM Thickness	Price LE/m^3
BioPCM® M182/Q29 Concentrated	422.21
BioPCM® M182/Q29	422.21
BioPCM® M182/Q27	10,557
BioPCM® M182/Q25	10,557
BioPCM® M182/Q23	823.25

5.4. PCM Optimization Tool Results

The building model from design builder primary IDF is used to start optimization using the new PCM Optimization tool. The tool will take its required time to run to finalize all stages and start optimizing the data. The run sequence goes through 3 steps. **The tool** uses the base case to identify 8 optimum types of PCM as shown in Figure 9.

The optimization process main control is the UMLH, if it is less than or equal to 300, then the simulation is performed. The tool runs 25 cases at 3 main stages, the PCM optimization tool output comes out with 8 optimized cases for the user to take the decision with the optimum case. If no changes are made in the model, the simulation from step 3 may be considered final. The PCM optimization tool output comes out with 8 optimized cases for the user to take the decision with the optimum case and visualized in a table and parallel coordinate plot as shown in Table 4 and Figure 10. In this study the medium office building used from design builder was chosen to complete the new multi-objective tool developed by the researcher to choose the optimum case. The tool made several runs, all cases have Thermal comfort less than 300 hour according to ASHRAE standards. All chosen cases are compatible, 1 case of optimum solutions is used Airgap inside-m182q29concentrated-0.22 to apply nZEB. This case shows 86.3hr of unmet and 626039.2 KWH total site energy.

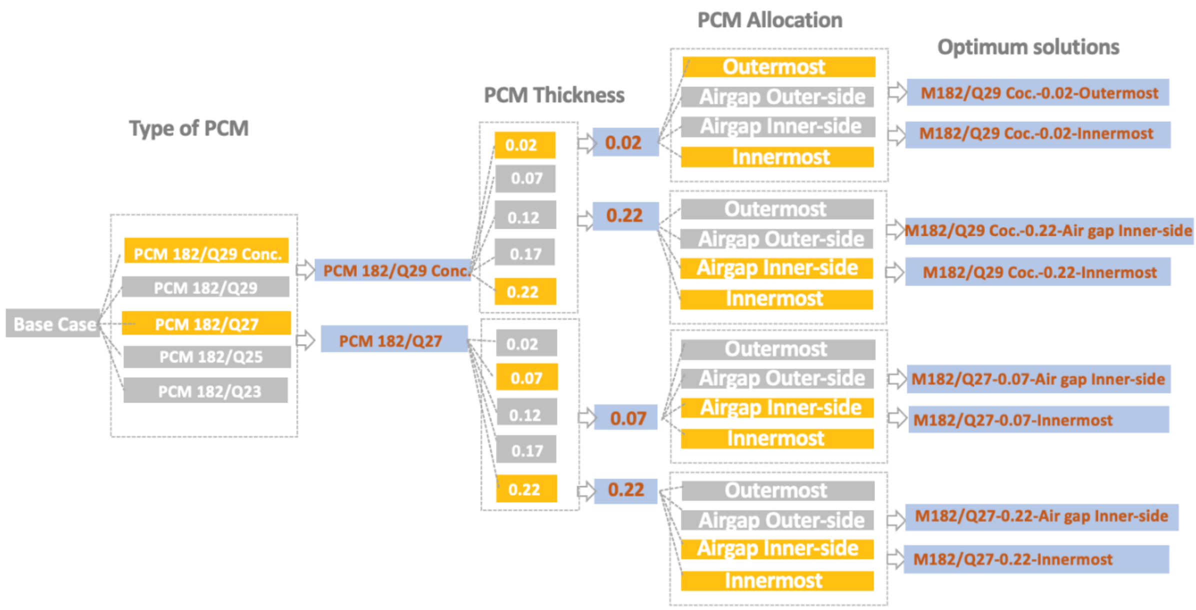


Figure 9. PCM Optimization Tool Flow for the pilot study model

Table 4. PCM optimization tool run results

Initial_cost L.E	Total_energy Kwh	Thermal_comfort hr	Running_cost L.E	Heating Kwh	Cooling Kwh	Name
1979015.2	634005.6	206.2	1014408.9	4908.7	629096.8	Innermost-m182q27-0.07
6219762.1	628055.8	86.2	1004889.3	3384.2	624671.6	Innermost-m182q27-0.22
22613.6	639791.1	171.7	1023665.8	4599.6	635191.5	Innermost-m182q29conc.0.02
248749.2	625860.3	86.9	1001376.5	2356.9	623503.4	Innermost-m182q29conc.0.22
248749.2	626039.2	86.3	1001662.7	2289.7	623749.5	Airgap inside-m182q29conc.0.22
22613.6	634509.5	140.2	1015215.1	5590.5	628919	Outermost-m182q29conc.0.02
6219762.1	628192.3	85.5	1005107.6	3313.6	624878.7	Inside-m182q27-0.22
1979015.2	634009.7	202	1014415.5	4831.2	629178.5	Airgap inside-m182q27-0.07

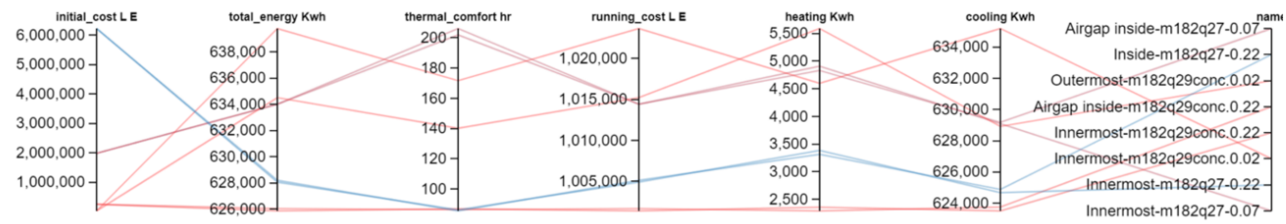


Figure 10. 8 optimized cases parallel plot coordinate

5.5. Reaching nZEB with PV

The designed tool covered the design optimization of applying a passive technique of active material to office building envelope. To achieve nZEB an active strategy should be applied to the building to be self-sustained and does not depend on the grid energy. This type of passive treatment is essential as the building thermal load to interior is the most critical among the others. Controlling the heat flow of opaque building construction is a key tool to reach suitable thermal comfort to meet the occupants. The HVAC consumes energy to control the amount of heat and cool gained by the envelope where this energy is taken from the grid.

A MATLAB code is conducted to optimize the Energy needed using PV and the cost. To achieve nZEB, the PCM optimized model is used to determine the total annual HVAC demand. with thickness of 7 cm in the innermost of the building. This model reach energy consumption from HVAC heating and cooling 626,038.2KW/h which is less than the code best practice, the total unmet hours equal to 86.0 hour less than code practice. The annual energy output for installing PV on opaque building envelope including roof and walls is 0.62 GWh with a total estimated cost of US $ 1.2 M as shown in Figure 11.

This design option of obtaining active and passive technique results in producing the energy needed due to the HVAC energy consumption. This makes the medium office building cover the annual energy demand of HVAC loads and achieve nZEB.

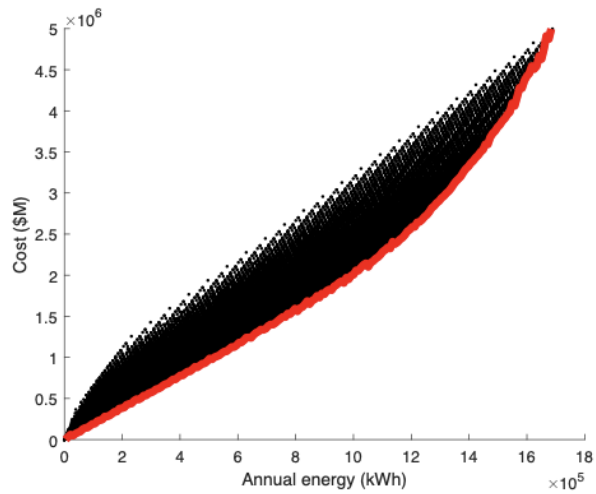


Figure 11. Total PV system cost (US$) and annual electrical energy generated (GWh). The solid line follows the lowest-cost solution for each given needed amount of annual PV energy output, while the black dots represent each design choice. With an optimized building model, the dotted lines show the chance of obtaining NZE for the building.

6. Results and discussion

This research aims to test the impact of different PCM material and position in opaque building envelope on Thermal comfort, energy, and cost. The goal was to develop a new methodology for the optimizing of PCM application in the opaque building envelope based on commercial buildings to understand the Thermal control of the building and how the material can affect Thermal comfort, energy consumption and cost to reach optimized cases and compensate the energy used to develop a nZEB. With a focus on the ideal Thermal comfort, position of the PCMs' application in the wall, initial cost of PCM, and operating cost of building energy, the optimization tool employs a multi-objective methodology to optimize the PCMs' application in building walls.

One of the major strengths of this tool is using a PCM multi-objective function optimization tool. PCM Optimization tool is a freeware, which can tackle multi-objective optimisation issues with automatic constraint processing, and which is coupled with numerous building simulation programmes. On the other hand, it makes an attempt to reduce any additional difficulties when connecting. It has a group of inputs to be entered by user, then it produces a schedule of the result and parallel coordinate plot, which helps the user understand different building outputs to be able to choose one of the optimum solutions. The user can access the tool from the link https://github.com/Mennahassany/PCM-Optimization-tool-.git.

The PCM Optimization tool is used to run the PCM simulated model from design builder to apply optimization. The tool showed a promising result for the tested office building. All primary chosen cases Thermal comfort were less than 300 hr, which means all cases reached Thermal comfort according to ASHRAE standards. The optimization passes through three main stages, to optimize 8 cases, each iteration directly tries to improve the results obtained by the previous iterate. The tool 3 stages are the material type (Different PCM specifications), PCM thickness and PCM allocation in the opaque wall envelope. The results show the following:

- Higher PCM melting point is better in the context of Cairo. This is due to high temperature in Cairo that requires higher melting point to be effective.
- This was in some of the previous work contribution.
- Material thickness result was a bit unexpectable, as the performance at 0.02, 0.07 and 0.22 m with different melting points showed good performance. Although simulation tool (Design Builder) has a default thickness of 0.07m and this thickness was not fixed for all results, therefore thickness has a high impact that must be simulated rather than recommending a specific number.
- The proposed optimization tool has more flexibility in the thickness.
- Material allocation was a debatable issue in previous works, the optimization simulation showed a good performance in the innermost, inner side- airgap and outermost. Therefore, the PCM allocation cannot be fixed unless simulated to determine the optimum desired output.

This shows that the building-controlled design cases must be performed through iterative procedures in which each iteration show different result that reduces time and shows different optimized results.

7. Conclusions

PCM Optimization tool is generated using Python 2, it uses a multi-objective function to optimize more than one variable.

- The allocation of material in the wall construction cannot be a tested variable in other optimization tools.
- The sequence of layering building materials in the wall envelope is a new implementation as an optimization variable.
- The study used an idf model generated from design builder software to optimize different variables including the allocation of PCM in the building envelope, the PCM thickness and type of PCM according to melting point.
- The optimization objectives were set to (Total Site Energy, Heating, Cooling and Thermal Comfort). The design variables used the Optimization tool needs high processing machine to run faster, as each iteration takes around 15 minutes.
- Also, the tool could not control building orientation as a variable, if this variable is added the better results can be reached.
- Therefore, for any PCM’s application in building’s walls, an evaluation with the help of the PCM Optimization tool will help designers in the decision making of the optimum design using PCM in the opaque wall envelope.

Finally, the PCM is a special material that responds in a different way than other insulation materials, it is not easy to predict the outcome of the material as there are always a group of variables. It is recommended to test each building using PCM material and apply optimization to reach better results and building performance, using an open domain access tool. This will help designer engage in the optimization process to reach better building performance with minimum effort and time.

All new buildings must be nearly zero-energy buildings as an international approach appears/shows/applies in the current time. To reach a well performed PVcells it is recommended to use a MATLAB code to optimize the use of the consumed energy in the office building in Egypt.

List of Abbreviations

PCM: Phase Change Material
BPO: Building Performance Optimization
BEO: Building Energy Optimization
MOO: Multi-Objective Optimization
nZEB: net Zero Energy Building

PV: Photovoltaic
HVAC: Heating, Ventilation and Air Conditioning
KW: Kilo watt
UMLH：Unmet Load Hour
TES: Thermal Energy Storage

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