



## **Greening Existing Educational Buildings in Egypt: A Decision Support Model for Optimizing Retrofit Strategies**

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**Abstract:** Financial constraints, progressive demands for higher and extended level of service is widening operational challenges for facilities managers (FM). The initiation of a project retrofit always require extensive calculation and scenario modeling to attain the optimal state of building operation from a financial, aesthetic and environmental perspective. This research presents a framework development of a decision support model to help decision makers in the selection of the best scenario to achieve the best return on investment (ROI). The energy simulation models are utilized to test retrofit alternatives and are constructed utilizing data collected from the building preliminary survey, retrofit decision scenario information from interviews with the building operations team, energy bill readings, and the relevant building construction technical data. A mathematical model ERDSS (Energy Retrofit Decision Support Model) is developed and integrates energy simulation in the algorithm, hence, a list of possible retrofit actions is created. The framework is part of ongoing research to test the applicability of the model to evaluate different alternatives for typical educational buildings in the context of the budget constraints and technical limitations. A case study is presented and the results show the model output falls within acceptable limits used in planning and budget forecasting. The added value of the model to the FM routine is the ability to utilize energy simulation combined with campus data in a simple interface to advance the decision making ability and allow for a seamless implementation of green building retrofit strategies.

### **1 Introduction**

The primary objective for FM is to maintain a steady, attainable balance between the provided services' portfolio and the incurred expenses. Consequently, a fundamental commitment by institutions such as higher education is to attain higher ranking by providing the best teaching and research space for their primary users comprised of faculty and students. The increased fiscal pressure on their yearly budget planning pose various operational challenges and requires a higher level of expertise and at times risk taking in allocating the proper budget investments in the different capital projects. The priority retrofits sometimes are due to deteriorated infrastructure, research requirements or promoting better learning environments. A continuous need is always in demand to use state of the art tools and decision support methods that can assist in allocating budget to the proper projects thus optimising the value added for the university for the best use of the funds and in the same time to achieve the primary academic goals set to maintain ranking, accreditation and a number of other requirements. To cope with the environmental needs and the institution commitments towards climate neutrality, green retrofits are implemented to provide bolstered air and water quality, minimize waste, and replace non-renewable energy resources with renewable sources (Duah & Syal, 2016). Such retrofits provide the needed upgrades to the space and in the sometime maintain the institution objective towards a sustainable campus environment. Accordingly,

the research presented in this paper is to design a decision support tool to allocate budget while integrating energy performance using simulation tools and mathematical modeling.

## 2 Background

Existing building green retrofit tend to maximize the energy performance of the built environment (Jaggs & Palmer, 2000). Several studies indicate a projected growth in green retrofitted existing buildings in the coming 20-25 years (Duah & Syal, 2016, Al-Badry et. al 2017). According to the literature, several types of retrofitting are used depending on the level of technical aspects and financial constraints: operation and maintenance measures, Standard retrofits and Deep retrofits (Liu et al., 2011). For existing buildings, a retrofit plan should investigate several factors that include building condition, current operating schedule, system efficiency, energy rates, targeted savings, occupants' needs, and available retrofit budgets (Wang et al., 2012). These factors present different variables with multiple criteria that affect the decision-making process and have a reciprocal impact on each other. Accordingly, the weight of each variable is important to calculate the impact on the final retrofit decision. This generated the need for a decision support tool that can help to prioritize different retrofit measures and to identify the optimum retrofit scenario within a target budget. Throughout the process of selecting the retrofit technologies and modeling tools, a number of factors need to be considered. These factors include: the level of available data, building age, condition of systems and nature of retrofit priority (cost, schedule and budget). This paper presents a framework for the development of a tool to prioritize the retrofit options according to the expected maximum energy saving with respect to budget requirements.

### 2.1 Sustainable building retrofit

A sustainable building retrofit allows for optimized operation with minimal environmental load. This includes the investigation of preliminary steps to achieve a higher level of efficiency (Arias, 2013). The retrofit process must go through specific phases as shown in Figure (2-1).

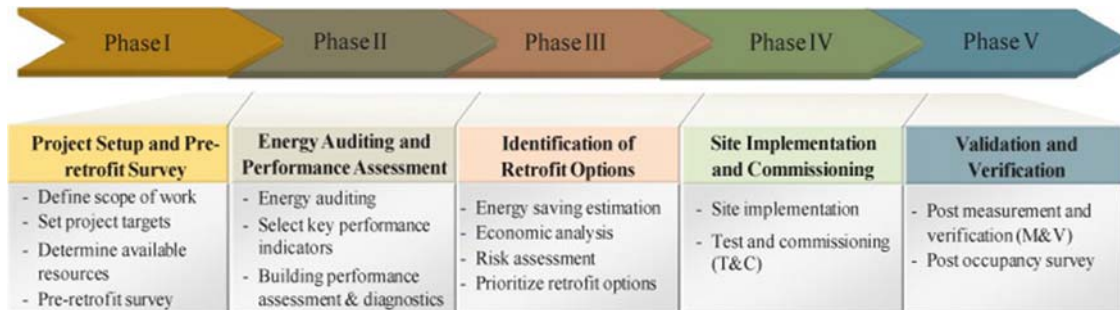


Figure (2-1) Key phases in sustainable building retrofit program (Zhenjun et al., 2012)

In addition, the trade-off between retrofit costs and energy savings must also be taken into account in order to develop an appropriate analysis of the designated retrofit options (Jaggs & Palmer, 2000).

### 2.2 Energy performance diagnostics

It is critical to consider energy performance and integrate it with a sustainable energy retrofit strategies as it provides different levels of data inputs for faulty diagnoses at a system level. (Oree et al., 2015) recommended a measurement based calculation assessment approach to produce reliable measures.

## 3 Research Framework

The proposed research framework builds up upon the previous outlines the building energy simulation and explains the steps for developing the prototype decision-support system where it consists of five main modules: Preliminary survey, Building evaluation, Model development, and ERDSS (Energy Retrofit

Decision Support System) scenario module. ERDSS is developed using *LabVIEW* software. Figure (3-1) shows the proposed framework and the main modules:

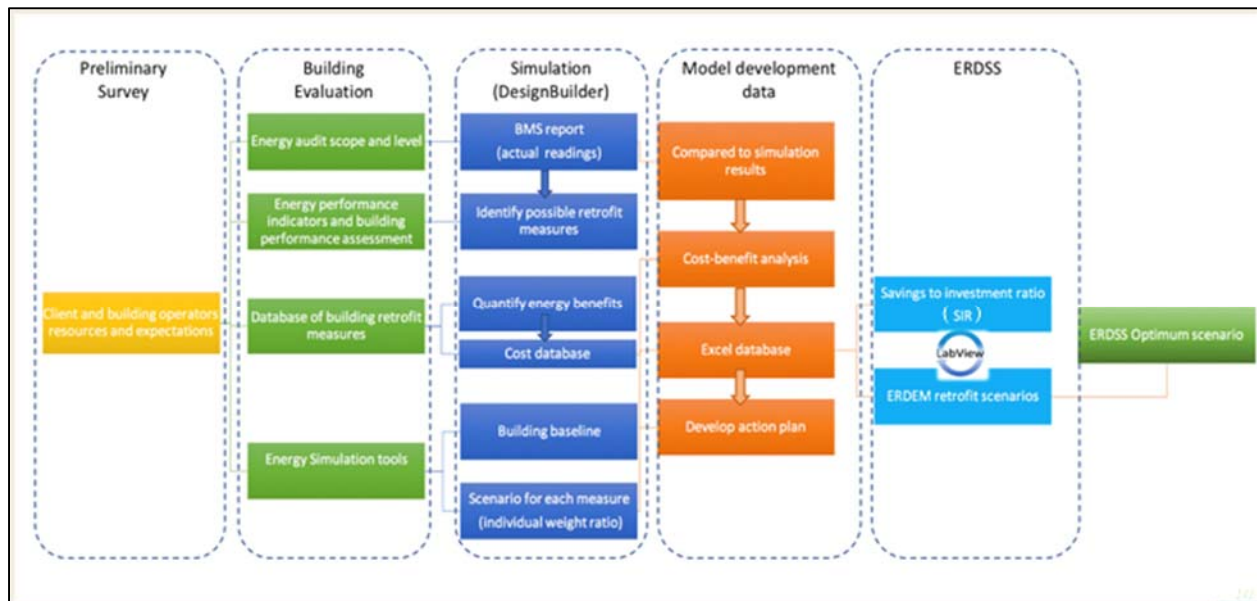


Figure (3-1) Proposed Framework

### 3.1 Preliminary survey and building evaluation modules

This module covers the collection of building information to assemble in the relevant working database. The preliminary data functions as baseline to reflect the current building conditions, and then to be compared with energy readings after retrofit implementation. Data collection includes interviews with the building operations team to identify the potential areas of improvement. After the database development, performance evaluation and energy audit take place in order to assess each system condition and efficiency. The audit outcome identifies possible areas that need improvement from an operational perspective.

### 3.2 Energy simulation and model development module

Essentially, simulation modeling is an emulation of the real building or system's operation over a specified time period. The aim of using the energy simulation is to identify the weight of each retrofit measure and its impact on the retrofit scenario to calculate the predicted building savings in energy. The data input varies from building location data, layout module, building usage activity, construction material, opening dimension, plug loads, equipment intensity and lighting schedules. The model development process can be summarized into six steps: Dynamic programming, user interface development, interactive database development, savings calculation analysis and optimization engine. A simulation baseline scenario is applied and compared to actual readings for a building to identify the simulation factor of error. The model core optimization engine is developed using *LabVIEW*.

### 3.3 Simulation retrofit scenarios module

ERDSS works through savings calculations for the selected retrofit scenario within the budget limitations, and the optimization engine generates multiple retrofit options and recommends the optimum scenario. After performing the preliminary building survey and defining the potential areas of improvement, the retrofit team identifies the applicable retrofit measures. The next step of the simulation is to test the impact of each retrofit measure individually. The impact of changing a given measure is assessed in different retrofit scenarios, by varying only that measure in the simulation while holding all other input measures constant.

The simulation model Figure (3-2) calculates the expected energy savings and can be used as an indication of the estimated financial savings over the lifetime of each retrofit design.

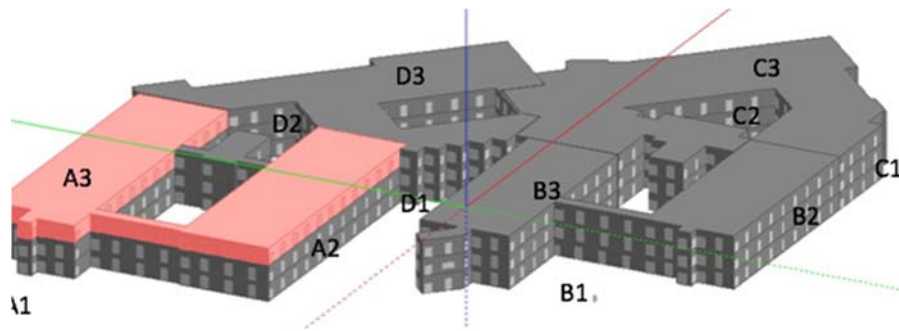


Figure (3-2) shows a sample applied case study model with data integration in *LabView*

The following equations are applied to calculate the expected savings:

[1]  $S_X = O - O_X$ , where

- $S_X$ : Expected annual energy saving in kWh
- $O$ : Overall annual energy consumption in kWh (baseline)
- $O_X$ : Energy consumption after applying retrofit measure in kWh

[2]  $SC_X = S_X * E_R$ , where

- $SC_X$ : Expected annual cost savings in LE<sup>1</sup>/ kWh
- $S_X$ : Expected annual energy saving in kWh
- $E_R$ : Energy unit rate in LE

[3]  $W = S_X / O * 100$ , where

- $W$ : is the weight of measure impact percentage on overall consumption
- $S_X$ : Expected annual saving in kWh
- $O$ : Overall annual energy consumption in kWh (baseline)

### 3.4 Decision Support System database development

DSS database development combines the collected information and contains the comparison results between the annual energy consumption simulation output and the actual annual energy consumption measured using the Building Management System (BMS) readings and energy bills records to identify the factor of error between simulation output and building consumption actual readings. In addition, the database includes the weight ratio calculations for each retrofit measure to identify each measure impact on the overall energy consumption of the building along with the calculation of the expected savings, each zone activity, operation schedule, temperature set points, and initial cost and life time for each retrofit measure. After comparing the building's overall energy consumption simulation data with the BMS actual readings, the following equations identify the simulation factor of error to be considered within the model calculations:

[4]  $B_A / B_{SR} = F_E$ , where

- $B_A$ : Building actual annual energy readings in kWh
- $B_{SR}$ : Building simulation annual energy in kWh (baseline)
- $F_E$ : Factor of error

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<sup>1</sup> The Egyptian pound is frequently abbreviated as LE or L.E., which stands for livre égyptienne (French for Egyptian pound)

The expected energy annual saving after applying retrofit measure can be calculated in kWh as follow:

$$[5] SM_{\eta} = B_S - BM_{\eta}, \text{ where}$$

- $SM_{\eta}$ : Measure “ $\eta$ ” annual energy savings in kWh
- $B_S$ : Building Simulation annual energy in kWh (baseline)
- $BM_{\eta}$ : Building Simulation annual energy after introducing measure “ $\eta$ ” in kWh

The resulting simulation savings multiplied by the factor of error:

$$[6] SM_{\eta} * F_E = PM_{\eta}, \text{ where}$$

- $SM_{\eta}$ : Measure “ $\eta$ ” annual energy savings in kWh
- $F_E$ : Factor of error
- $M_{\eta}$ : Predicted annual energy savings for measure “ $\eta$ ” in kWh

Energy Use Intensity “consumption per m<sup>2</sup>” is equal to total energy consumption divided by the total area:

$$[7] EUI = B_A / T_A, \text{ where}$$

- $B_A$ : Building actual annual energy readings in kWh
- $T_A$ : Building total area “conditioned” in m<sup>2</sup>
- $EUI$ , Energy consumption per m<sup>2</sup> (kWh/m<sup>2</sup>)

Building total actual energy consumption  $EUI_{\eta}$  after applying retrofit measure “ $\eta$ ” is divided by the total area to calculate the revised energy consumption after applying the measure:

$$[8] EUI_{\eta} = BM_{\eta} / T_A, \text{ where}$$

- $B_A$ : Building actual annual energy readings in kWh
- $T_A$ : Building total area “conditioned” in m<sup>2</sup>
- $EUI_{\eta}$ : Energy consumption after applying measure “ $\eta$ ” per m<sup>2</sup> (kWh/m<sup>2</sup>)

Finally, predicted annual savings for measure “ $\eta$ ” are divided by Building actual annual readings to identify the weight ratio for measure “ $\eta$ ”:

$$[9] PM_{\eta} / B_A = WM_{\eta} \%, \text{ where}$$

- $PM_{\eta}$ : Predicted annual energy savings for measure “ $\eta$ ” in kWh
- $B_A$ : Building actual annual energy readings in kWh
- $WM_{\eta}$ : weight ratio for measure “ $\eta$ ”

The Excel database contains all the results of applying each measure individually. This provides the ERDSS framework with all the needed information about the selected measure to facilitate cost calculation relevant to square meter area to be adapted to different building areas. It also contains the estimated initial cost for each measure. Cost data collected from the local market depends on actual price quotations and vendor price lists. The ERDSS considers the annual energy calculations from the building energy simulation software and uses it to compare the effect of different retrofit measures on educational buildings. ERDSS uses Savings-to-Investment ratio (SIR) as a ranking tool to help the prioritization process of selecting the optimal green energy retrofit scenario.

### 3.5 Savings to Investment Ration

In order to calculate the SIR, first the model finds the total present value of energy saved quantity. A present value approach allows cash flow calculations over the retrofit life span, while considering the cost-equivalent value relative to current prices, in order to adjust future expected savings to their equivalent present value. Each section is calculated individually. The impact (i.e. weight) of each retrofit measure is selected by the user then it is converted into an annual value of energy saved after applying the simulation factor of error using the energy unit costs (user input) and the measured lifetime in years.

[10] Present value is calculated as:  $PV_C = C \left[ \frac{1}{r} - \frac{1}{r(1+r)^t} \right]$

- PV<sub>C</sub>: Present value
- r: inflation rate (user input)
- C: Expected annual cost saving in LE
- t: Lifetime of measure in years

Then, the expected annual saving kWh [S<sub>x</sub>] is calculated using equation [1] and the expected annual savings in LE is calculated using equation [11]

[11]  $C = S_x * E_R$ , where

- C: Expected annual energy saving cost in LE
- E<sub>R</sub>: Energy unit rate (user input) in LE / kWh

The final step is to calculate the SIR

[12]  $SIR = PV_C / I_x$

- PV<sub>C</sub>: Present value of the total lifetime energy savings
- I<sub>x</sub>: Investment cost for retrofit measure in LE

The model calculates the expected savings resulting from the application of the retrofit measures and the expected savings per meter square (m<sup>2</sup>) in order to conduct the calculations for different spaces within the same building parameters. The optimum scenario is formulated through an optimization problem. The variables represent the different retrofit alternatives of different building systems.

#### 4 Scenario generation and user interface

ERDSS provide a data input interface to allow for data storage and analysis. The first approach helps the user to identify the retrofit measures that can be applied for the selected building and need to prioritize the retrofit measures plan according to the expected SIR order. The second approach is a scenarios generation screen where it provides the user with all the possible retrofit scenarios for this building arranged according to SIR within the allocated budget. The optimization engine selects measures from the database according to the building area, current energy consumption, and budget limitation. The model is designed to calculate each measure initial cost and the expected SIR. The user can select and receive a detailed report for it as shown in figure (4-1). A number of operational measures with no investment cost can be extracted. An optimization report presents the retrofit scenario measures and their calculations (i.e.: expected annual energy savings, annual savings cost, investment cost, total lifetime savings, SIR priority, and conformity with the given budget) which will be also generated. The second level of needed information is related to retrofit alternatives such as, building envelope, windows, and glass type. For the HVAC sub-screen, data including interior summer and winter indoor temperatures, operation hours, and list of systems. Finally, after the data input is entered through the (ERDSS) model, the optimization engine runs to select an optimum retrofit scenario that maximizes the SIR ratio then prioritizes the other scenarios accordingly within the budget limitations. The user's selection depends on building condition and covers the area for improvements.

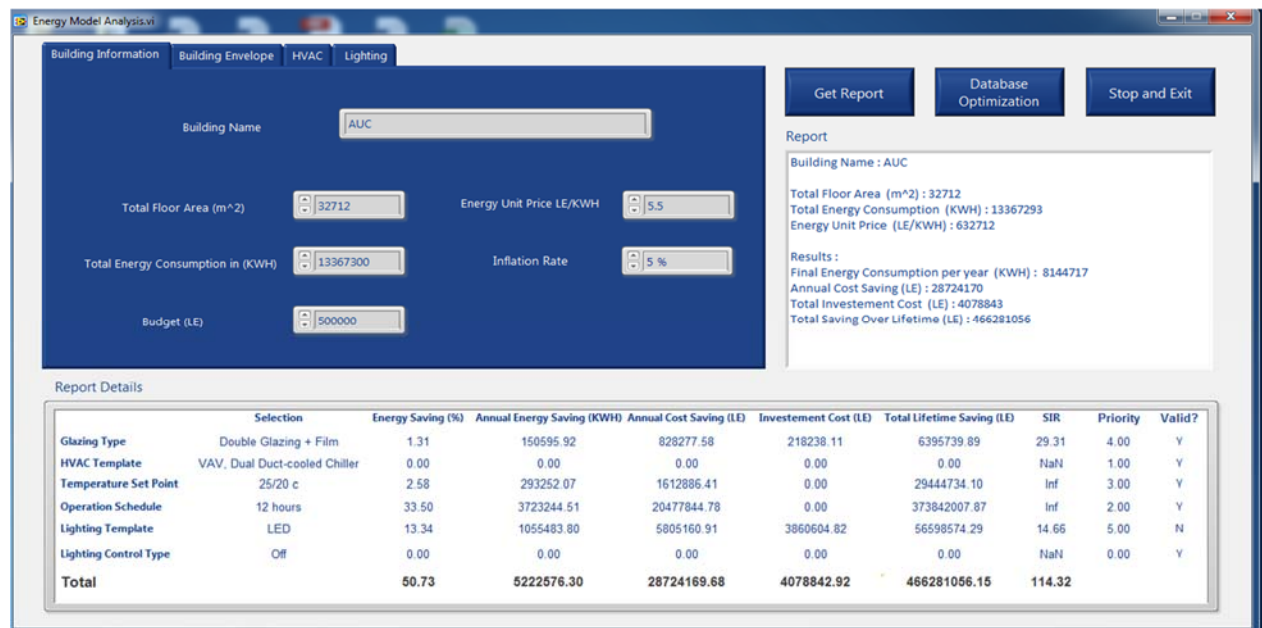


Figure (4-1) ERDSS Scenario generation

## 5 Summary

The retrofits approaches vary from one building to another and is a continuous challenge to building managers worldwide. The range of retrofit measurements generates a large number of retrofit alternatives which poses a challenge to prioritize selections by building operators. The retrofit scenario selection depends on the trade-off between initial retrofit cost and expected energy savings. An energy retrofit decision support tool was developed to help decision makers to select the retrofit scenario which can achieve the highest energy savings within the allocated retrofit budget. In this paper, the integrated Energy Retrofit Decision Support System (ERDSS) framework with optimization features are presented for an existing educational building. The model was used to recommend the optimum retrofit scenario within the budget constraints and will be applied on a case study and validated in future publications. ERDSS was developed using *LabView* software in parallel with the use of energy simulation to generate output results and store it in an energy database library that are later used to achieve optimum solutions.

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