ISSN 2229-5518

# Reducing Energy Consumption in Residential Building Using Architectural Low Energy Solutions

Mamdouh A. Mohamed, Dr. Asmaa N. Elbadrawy, Prof. Lamis Elgizawi.

**Abstract**—Energy saving is the way for developing countries to achieve sustainable development, in recent decades the energy problem has become more difficult, especially in the residential building sector, which consumes nearly 40% of the total energy in Egypt, while providing new opportunities and pillars for the development of future generations.

This research aims to identify best practices and initiatives related to low-energy buildings solutions and to manage them in residential building, as well as to highlight the shortcomings in the development of energy policies and access to ways of saving and managing energy, which is one of the contemporary challenges in Egypt to achieve sustainable development.

Also adopts a practical approach based on reviewing existing literature on saving energy and efficiency building, and the best ways for energy saving by simulating various scenarios using Design Builder (DB) software for a residential unit in one of the new communities in Egypt, studying the impact of the selected elements used in design according to the low-energy buildings solutions, and analyzing the results and discussing the recommendations necessary to achieve the optimal energy saving, Where's that? Energy saving is a developing approach is inevitable to meet the demand of future generations and sustainable development.

**Index Terms**— Energy Saving, Energy Efficiency, Low-energy Building Solutions, Design Builder (DB) software.

## 1 INTRODUCTION

The current consumption rates, the world faces the risk of depletion of natural resources, in addition to the environmental harm resulting from the use of carbon-producing fuel sources. Consequently, of the environmental damage resulting from rapidly growing and industrialization in the 19th century, an environmental effect of buildings become a widely concern, which obvious as a beginning of ecological design as known these days. Energy efficiency issue become one of the most important attempts from this century because of increasing energy demand and limited resources. Residential building can make major contributions to a sustainable energy reduction, by public awareness of the importance of energy efficiency.

Recently, new efficient appliances, building technologies, legislation quantifying building regulations to include the total built environment. further, Continuing improvements are likely led to the adoption of small-scale renewable technologies embedded in the building construction for building saving energy.


- *Mamdouh A. Mohamed is currently pursuing PhD degree program in architectural engineering in Mansoura University, Egypt, PH-01009950479. E-mail: mmdouh@mans.edu.eg*
- *Dr. Asmaa N. Elbadrawy is currently a lecturer in architectural engineering department in Mansoura University, Egypt. E-mail: asmaaelbadrawy@gmail.com.*
- *Prof. Lamis Elgizawi is currently a professor in in architectural engineering department in Mansoura University, Egypt. E-mail: lamiselgizawi@yahoo.com.*


## 2 STATEMENT OF THE PROBLEM

Energy efficiency (EE) is a cost-effective means of ensuring energy economy by minimizing the unit resource input per unit output, it can be subdivided into parts namely economic and efficiency. In the economic view, it is the measure of improvement performance or increased more energy efficiency equipment, conservation and altering consumer attitudes.[1]

In Egypt residential buildings consumed approx. 40% of total energy consumption, this are consumed by HVAC and lighting systems. in that order, the increasing energy cost, government decision for energy efficiency, and increasing human comfort, shading tools and natural ventilation controlling to make effective use of natural resources that can minimize energy consumption.[2]

### 2.1 Research aim

Studying the low energy building solutions, analyzing, by selecting the most important solutions to apply them to the case study selected using DB simulation software to evaluate their influence on total energy consumption for the tested scenarios.

### 2.2 Methodology

The research assumes that the most important problems in the developing countries such as Egypt is energy, and how to reduce the consumption by architectural design methods as the first way to maximize energy reduction and select the most effective solutions for low energy building (residential unit, the most energy-consuming sector) for studying their impact on total energy consumption using DB simulation software, ending by analyzing and discussing the results to present the research recommendations.

### 2.3 why Design Builder (DB)

Design Builder is a progressive software tool for checking building energy, carbon, lighting, and thermal comfort performance. Developed to facilitate the building simulation, it allows you to quickly compare the performance of building designs and deliver results on time and within the budget.[3] DB software is an interface of Energy Plus which is an authoritative and validated and wide used by research community.

## 3 Low Buildings Solutions Strategies

Recently low energy buildings gained the attention with a large-scale in residential sector, so national and international criteria for energy use have become stricter. NZEB (Nearly Zero Energy Buildings) has been targeted by European union through directive imposed on member states to adapt building regulations, which by 2021 should be new standard for buildings. Egypt also targets according to the National plan to improve the efficiency of the electrical energy. In 2030, the standard specifications for zero-energy buildings will be mandatory for all new buildings in Egypt and encourage the use of solar heating systems and PV to meet about 75% from the energy need in new buildings, while achieving energy efficiency standards in buildings to reach a consumption of 30 KWh/m2. Which lead to saves about 40% of total energy consumption.[4]


Fig. 1. Low energy building solutions categories.

According to task 40 (Net zero energy solar buildings NZEB) related to The Solar Heating and Cooling Technology Collaboration Programme (SHC TCP), there are three categories from solution as shown in fig.1, the most important categories related to the research is the architectural solutions, it is the first stage which begin from design stages.[5]

### 3.1 Architectural solutions

The architectural solution divided to 12 elements, according to fig. 2 there are 5 elemets the most effective architectural solutions as follow:[6]

3.1.1 **optimized building form**

a- Block distribution

The formation of the building's block, considering the climatic considerations of the site, affects Indoor and open thermal comfort. Some building patterns increase shading and ventilation, contributing to reduced cooling load. And it's different. Recommended mass distribution for warm, dry and warm climates Wet.[7] Fig.2.

| | Cooling Dominated | Heating Dominated | Mixed Cooling& Heating Dominated |
|---|---|---|---|
| Optimized building form | 100 | 93 | **92** |
| Thermal zoning | 50 | 43 | **8** |
| Advanced envelope | 100 | 53 | **83** |
| Advanced glazing | 25 | 5 | **17** |
| Passive solar gain | 50 | 93 | **67** |
| Thermal mass | 50 | 86 | **75** |
| Solar shading | 100 | 93 | **100** |
| Site vegetation | 50 | 0 | **8** |
| Natural ventilation | 75 | 36 | **92** |
| Ground cooling | 0 | 7 | **17** |
| Window to wall ratio | 50 | 57 | **58** |
| Skylights | 0 | 29 | **25** |
| Solar tubes | 25 | 5 | **17** |

TABLE 1. Architectural Solutions effective Ratio According to Task 40.

b- Outdoor spaces:

Provide an outdoor space helps to reduce ambient temperature and reduce the cooling loads of nearby buildings by using - plant elements to maximize shading - use of porous materials and light colors - shading at least 50% of the external spaces.

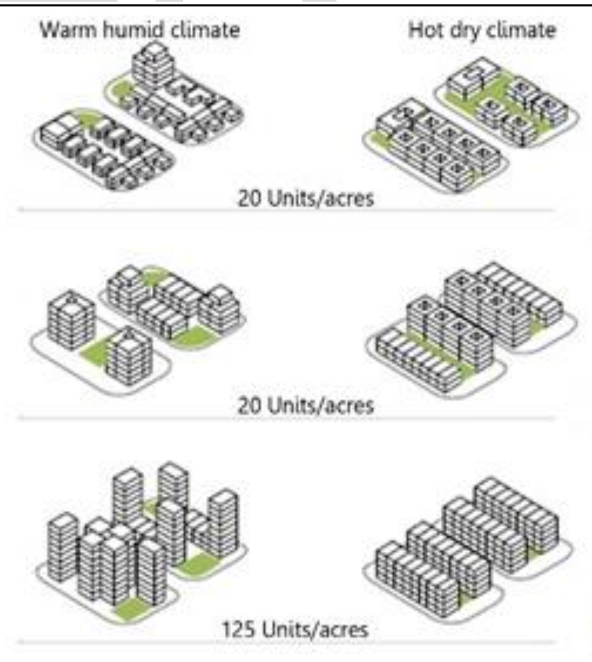


Fig.2. Mass distribution pattern according to densities for achieving energy efficiency.

c- Land division:

Flexibility should be maintained to provide a natural and

shaded environment and take advantage of passive design elements, which lead to the efficiency of cooling and saving energy.
Building form affected by ratio 92% in mixed cooling and heating dominated according to task 40 (Net zero energy solar buildings NZEB), it represents higher effective solution.[8]

3.1.2 **advanced envelope**
High performance building starts with the building envelope. Guided by physics and building science, building envelopes combine a simple suite of elements to control heat, air, and moisture and deliver superior efficiency, durability, comfort, and thermal comfort for occupants. Advanced enveloped affected by ratio 83% in mixed cooling and heating dominated according to task 40 (Net zero energy solar buildings NZEB), it represents higher effective solution.[9]

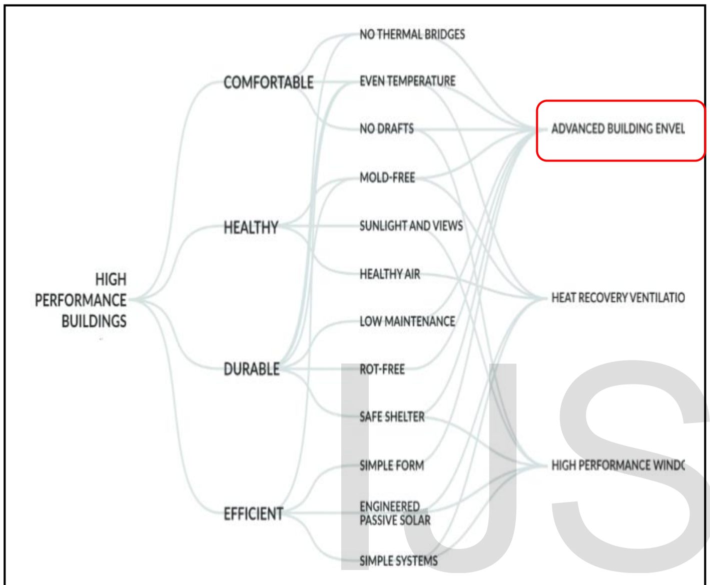

Fig.3. High performance building requires a holistic approach.

3.1.3 **solar shading**
Shading is the imperforate barrier of sunrays directed to the envelope. This varies in position and size, depends on the relationship of the sun rays and the building's envelope. [10]

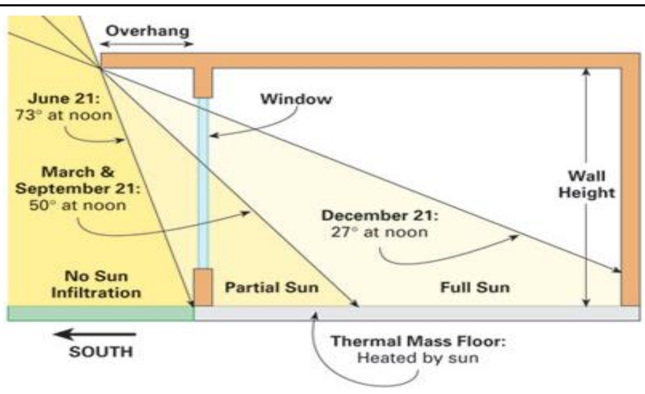

Fig.4. Shading unit and sun ray's relation with the envelope.

Solar shading affected by ratio 100% in mixed cooling and heating dominated according to task 40 (Net zero energy solar buildings NZEB), it represents higher effective solution.

3.1.4 **natural ventilation**
Using natural air force to supply fresh air into indoor spaces, as an alternative to mechanical ventilation. It may be divided to:

1. Controlled natural ventilation is a displacement of air through specified openings such as windows, doors, and ventilators. It is usually controlled to some extent by the users.
2. Uncontrolled ventilation (Infiltration) is the random flow of air through unintentional infiltration through cracks, gaps or crevices in building structure. *It is less desirable and can be controlled only by plugging the gaps.*[11]

There are a few guidelines for the best utilization of outdoor wind as the followings:

a. Site location and layout
b. Building shape
c. Building orientation
d. Heat slinks

Natural ventilation affected by ratio 92% in mixed cooling and heating dominated according to task 40 (Net zero energy solar buildings NZEB), it represents higher effective solution.[8]

## 4 CASE STUDY

The buildings selected carry typical design features for residential buildings in Egypt, which is repeated in the most of new cities all over Egypt, so the chosen Unit is in Al Shorouk City which is one of those new cities. Dar Misr is defined as Medium level Housing which is provided various models of housing programs to meet the growing demand and provide integrated services and quality of living to meet the medium levels of housing demands.

### 4.1 Cairo climate

In Cairo, the summers are hot, humid, arid, and clear and the winters are cool, dry, and mostly clear. Over the course of the year, the temperature typically from 10°C to 35°C and is rarely could be below 8°C or above 39°C.

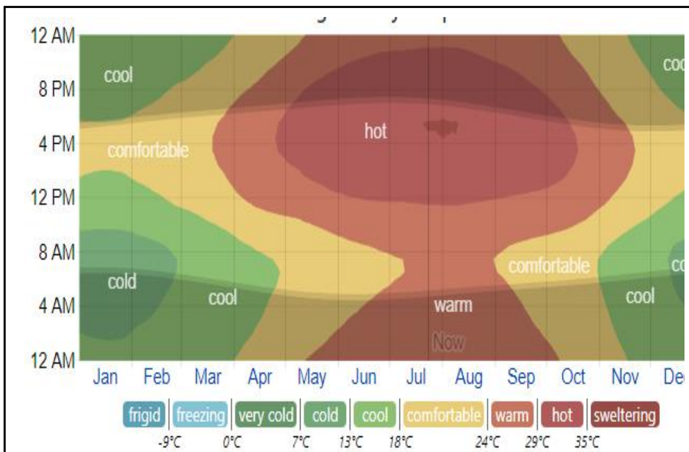

Fig.5. Average hourly temperature in cairo.

The wind is often from the north for 9.8 months (from February to December) with a peak percentage of 86% on August. also is often from the west for 2.2 months (from December to February) with a peak percentage of 35% on January.

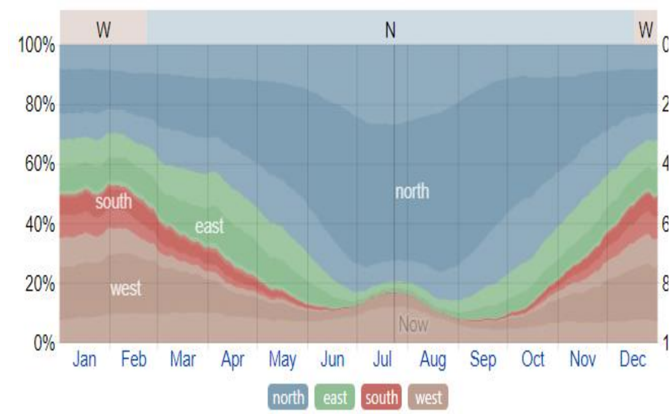


Fig.6. Wind direction in cairo.

## 4.2 Location

Location of the case study in 'Dar Misr, Al Shorouk City, Cairo, Egypt' one of the common clusters was selected as a case study for this research.

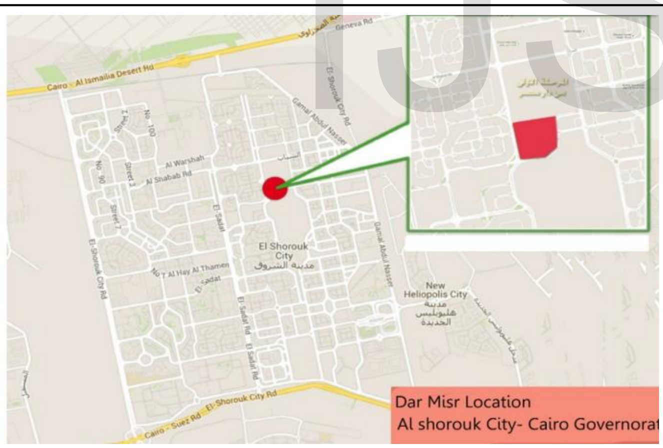


Fig.7. Dar Misr Layout, Al Shorouk City, Cairo.

The base case of the study has been evaluated is an existing building based on building's form, plans, orientation, and location.

## 5 Material

Materials used was modified according to the minimum requirements of Egyptian Code to Improve Energy Efficiency in Buildings (Residential Buildings): code No.306/2005, to obtain real base case. Al Shorouk City is in Delta and Cairo region according to the Housing and Building Research Centre (HBRC) which divides Egypt into eight different climatic design regions as shown in fig.8.

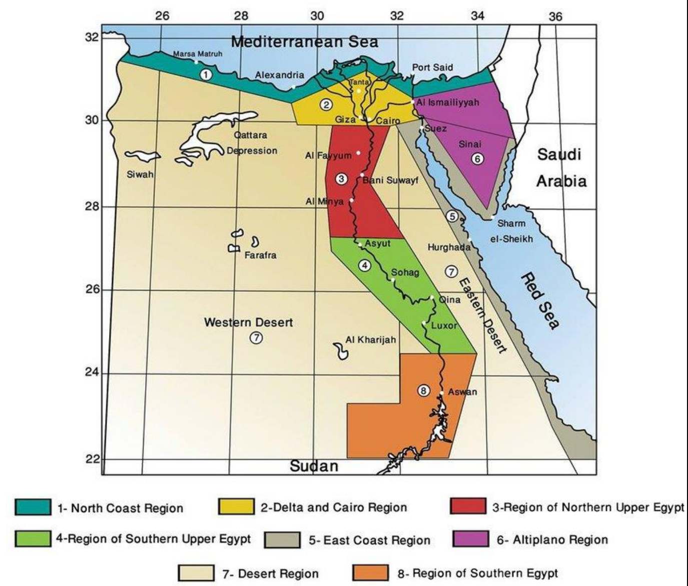


Fig.8. Classification of climatic zones in Egypt according to HBRC.

while the prescribed U-values are different for each climate region. In Delta and Cairo region, maximum U- value is 0.50W/m2K for the walls (U wall), 0.25 W/m2K for roofs (U roof), 0.4 W/m2K for slabs (U slab which equal 12cm reinforced concrete, 6cm sand, 2cm mortar and 2cm tiles) and 2.5W/m2K for windows (U window).[12]

Fig.9. Ground Floor

| Apartment No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Area($m^2$) | 115 | 130 | 130 | 115 |

| Unit Information | | | |
|---|---|---|---|
| No. of Blocks | 1 | No. of Apartments | 24 apartments |
| No. of Floors | 6 (Ground + 5 floors) | | |
| Floor Area/Block | 520 $m^2$ | No. of Units/Floor | 4 |
| Unite Area/Ground | 115, 130$m^2$ | Unite Area/Floors | 130 $m^2$ |

ISSN 2229-5518

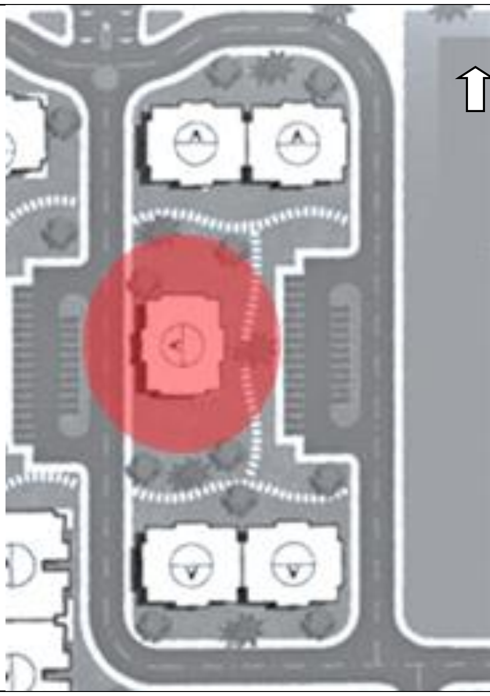

Fig.10. Case Study (Selected cluster)

Fig.11. Repeated Floor

| Apartment No. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Area(m²) | 130 | 130 | 130 | 130 |

Simulations give a reasonable and consistent results in comparison with the constructed building, and accuracy of computer-based energy simulations depends on the input parameters which should be assigned correctly. Knowledge and understanding about simulation software and building physics important to assess a validly of building, Design Builder Simulation program (DB) is an energy analysis and performance modeling software that offers a variety of custom modules designed to address different building performance workflows. DB can help you incorporate sustainable building approaches and analyses into your BIM projects which help to managing energy in building, using the weather data from IWEC for Cairo and allows to test various scenarios with many parameters for the cluster selected to calculate building energy use.[13]

## 6 Scenarios

This research uses computer-based energy simulation to manage and save energy for building, a residential cluster which reflects typical residential design feature in Egypt is selected for these simulations. While orientation, weather, site conditions, building form are selected as the existing case; envelope is tested according to minimum requirements EC No.306/2005.

| Case | No. | Orientation | Envelope | Ventilation /Cooling | Solar Shading |
|---|---|---|---|---|---|
| Base Case | 0 | E | IEEC(RB) 306 | Natural | None |
| Scenarios | 1 | E | IEEC(RB) 306 | Natural + Temperature setpoint | None |
| | 2 | E | IEEC(RB) 306 | Natural + Temperature Delta t Summer | None |
| | 3 | E | IEEC(RB) 306 | Natural | Daylight (on) CLR |
| | 4 | E | IEEC(RB) 306 | Natural | Outside Temperature (Summer) CLR |
| | 5 | E | IEEC(RB) 306 | Natural | Cooling (on) CLR |
| | 6 | E | IEEC(RB) 306 | Natural | Night Outside (Winter) HLR |
| | 7 | E | IEEC(RB) 306 | Natural | Night Inside (on) HLR |
| | 8 | E | IEEC(RB) 306 | Natural | Day Cooling + Night Outside |
| | 9 | E | Infiltration | Natural | None |
| | 10 | E | IEEC(RB) 306 | Natural + Temperature Summer | Day Cooling + Night Outside |

TABLE 2. Base case and different scenarios tested

## 7 Simulation

### 7.1 Base case Simulation

In base case (the existed case) after simulation in (DB), total energy consumption was 71985.75 KWh per year, the flow of heating inside was -291873.05 KWh, electricity used for lighting was 55813.2 KWh, the external infiltration was -457150.8 KWh through the buildings and the external ventilation from outside to inside was -179958.4 KWh.

ISSN 2229-5518

| Sn. No. | HEAT FLOW (KWh) | EXTERNAL VENTILATION (KWh) | HEAT FLOW (KWh) | LIGHTING ELECTERICTY (KWh) | TOTAL CONSUMPTION (KWh) |
|---|---|---|---|---|---|
| BASE-CASE | -291873.05 | -179958.4 | -457150.8 | 55813.2 | 71985.75 |

TABLE 3. Base case Simulation Results

## 7.2 Result Verification

7.2.1 Real Consumption for the case study

| Total | Average | Dec | Nov | Oct | Sep | Aug | July | June | May | April | March | Feb | Jan | Unit No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3232 | **269.33** | 253 | 228 | 277 | 288 | 287 | 296 | 275 | 264 | 242 | 272 | 280 | 270 | **1** |
| 2665 | **222.08** | 196 | 190 | 232 | 241 | 240 | 251 | 240 | 225 | 198 | 202 | 220 | 230 | **2** |
| 2618 | **218.17** | 203 | 209 | 222 | 247 | 255 | 265 | 270 | 201 | 191 | 180 | 190 | 185 | **3** |
| 1765 | **220.63** | 220 | 211 | 200 | 230 | 260 | 234 | 220 | 190 | 0 | 0 | 0 | 0 | **4** |
| 2627 | **218.92** | 203 | 178 | 227 | 233 | 237 | 246 | 225 | 214 | 192 | 222 | 230 | 220 | **5** |
| 2888 | **240.67** | 210 | 206 | 251 | 266 | 271 | 284 | 280 | 230 | 203 | 211 | 231 | 245 | **6** |
| 2712 | **226.00** | 201 | 196 | 236 | 240 | 241 | 257 | 244 | 227 | 203 | 207 | 225 | 235 | **7** |
| 2441 | **203.42** | 196 | 182 | 190 | 187 | 199 | 240 | 231 | 210 | 220 | 190 | 196 | 200 | **8** |
| Empty | **0.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **9** |
| 2408 | **218.91** | 193 | 186 | 218 | 229 | 240 | 251 | 260 | 218 | 194 | 201 | 218 | 0 | **10** |
| 1637 | **181.89** | 185 | 163 | 168 | 177 | 186 | 191 | 197 | 180 | 190 | 0 | 0 | 0 | **11** |
| 3225 | **268.75** | 246 | 233 | 248 | 276 | 286 | 303 | 299 | 261 | 251 | 258 | 273 | 291 | **12** |
| Empty | **0.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **13** |
| 3675 | **306.25** | 308 | 283 | 271 | 286 | 342 | 355 | 380 | 308 | 281 | 262 | 238 | 361 | **14** |
| 3415 | **284.58** | 348 | 274 | 280 | 292 | 335 | 316 | 323 | 260 | 220 | 213 | 180 | 374 | **15** |
| 2384 | **216.73** | 212 | 202 | 188 | 196 | 255 | 267 | 248 | 231 | 207 | 193 | 185 | 0 | **16** |
| 2902 | **241.83** | 230 | 214 | 208 | 259 | 263 | 294 | 286 | 233 | 219 | 243 | 227 | 226 | **17** |
| Empty | **0.00** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **18** |
| 2890 | **240.83** | 235 | 227 | 236 | 240 | 278 | 284 | 270 | 240 | 220 | 187 | 198 | 275 | **19** |
| 3269 | **272.42** | 247 | 266 | 257 | 265 | 287 | 295 | 297 | 268 | 270 | 262 | 274 | 281 | **20** |
| 3877 | **323.08** | 287 | 307 | 331 | 321 | 350 | 373 | 380 | 296 | 299 | 311 | 301 | 321 | **21** |
| 3853 | **321.08** | 313 | 309 | 322 | 313 | 330 | 344 | 357 | 286 | 300 | 321 | 325 | 333 | **22** |
| 3363 | **280.25** | 261 | 248 | 250 | 289 | 303 | 318 | 306 | 273 | 264 | 270 | 287 | 294 | **23** |
| 3555 | **296.25** | 290 | 288 | 284 | 301 | 320 | 340 | 360 | 256 | 250 | 280 | 286 | 300 | **24** |
| **61401** | **5272.067** | **5037** | **4800** | **5096** | **5376** | **5765** | **6004** | **5948** | **5071** | **4614** | **4485** | **4564** | **4641** | **Total** |

TABLE 4. Base case Real Consumption
Source: Ministry of Electricity and Renewable Energy.

We found 3 unit closed, the total consumption for 21 units is 61401 KWh.
To calculate the total real consumption, we calculate the average for unit per year as follow:

= 61401 / 21= 2923.86 KWh (for each unit)
Total real consumption= 24(unit) * 2923.86 (average for each unit) = **70172.64** KWh
After comparing total consumption for the base case resulting from simulation and the real consumption (71985.72/70172.64) The error ratio is 0.025% and it was acceptable to complete the simulation for other scenarios.

## 7.3 Result for 10th scenarios simulation

| Sn. No. | HEAT FLOW (KWh) | EXTERNAL VENTILATION (KWh) | HEAT FLOW (KWh) | LIGHTING ELECTERICTY (KWh) | TOTAL CONSUMPTION (KWh) |
|---|---|---|---|---|---|
| 1 | -252226.45 | -152847.6 | -443313.2 | 44616 | 54866.24 |
| 2 | -234896.2 | -145729.2 | -448757.6 | 43466 | 54567.86 |
| 3 | -159312.3 | -186597.2 | -384663.2 | 55813.2 | 87369.26 |
| 4 | -252047.25 | -187556.8 | -425557.6 | 55813.2 | 73927.59 |
| 5 | -265527.85 | -175093.6 | -442747.6 | 55813.2 | 73797.62 |
| 6 | -243192.95 | -178681.6 | -444483.2 | 55813.2 | 71090.66 |
| 7 | -252226.45 | -183999.6 | -443313.2 | 55813.2 | 72116.88 |
| 8 | -224151.9 | -149230 | -418154 | 43466 | 52314.18 |
| 9 | -321389.6 | -186871.2 | -248375.2 | 55813.2 | 53701.44 |
| 10 | -63796.95 | -119049.6 | -309278 | 43391.6 | 47200.21 |

TABLE 5. 10th Scenarios Simulation Results

Fig.12. According the result of simulation the most efficient scenario in heat flow saving was Sn. 10 which minimize to 78.14% from the base case. Generally, most of the seleted strategies system was effective in minimizing heat flow into the building with a various ratio between 9.03% and 78.14% except Sn.09 that was maximize tho 110.11%:

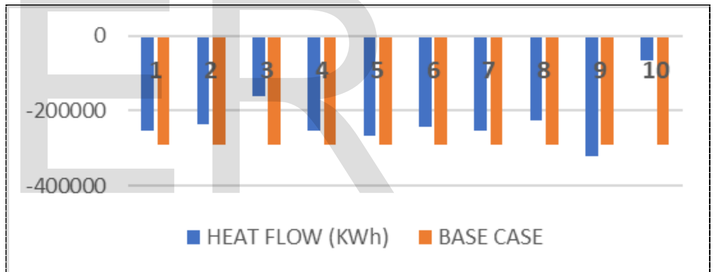


Fig.12. Heat flow comparison.

Fig.13. The most efficient scenario in external ventilation saving was Sn. 10 which minimize to 33.85% from the base case, and the worst scenario in external ventilation was Sn. 04 which maximize to 104.22% from the base case, generally Sn. 01, 02, 08, 10 the more effective in external ventilation with Sn. 10(the most effective scenario).

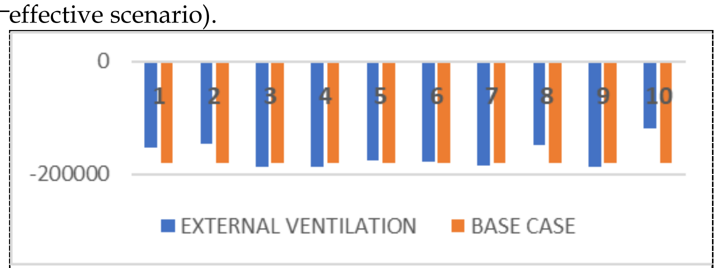


Fig.13. External ventilation comparison.

Fig.14. The most efficient scenario in external infiltration saving was Sn. 09 which minimize to 45.67% from the base case, then Sn. 10 which minimize to 32.35%, generally Sn. 03, 09, 10 effectives in external infiltration with ratio between 15.85 to 45.67%

with Sn. 09(the more effective in external infiltration).

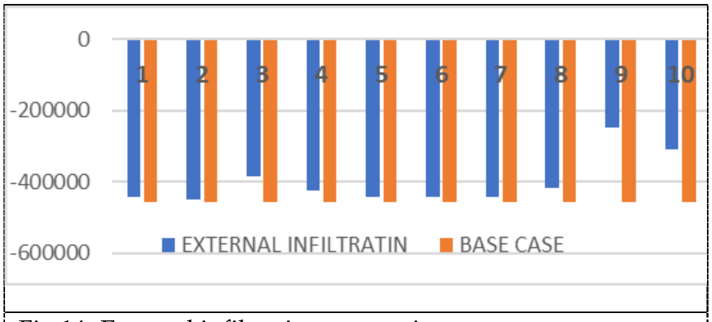


Fig.14. External infiltration comparison.

Fig.15. The efficient scenario in heat generation saving was Sn. 10 which minimize to 22.26% from the base case, generally Sn. 01, 02, 08, 10 the more effective in heat generation with ratio between 20.06 to 22.26% with Sn. 10(the more effective in heat generation).

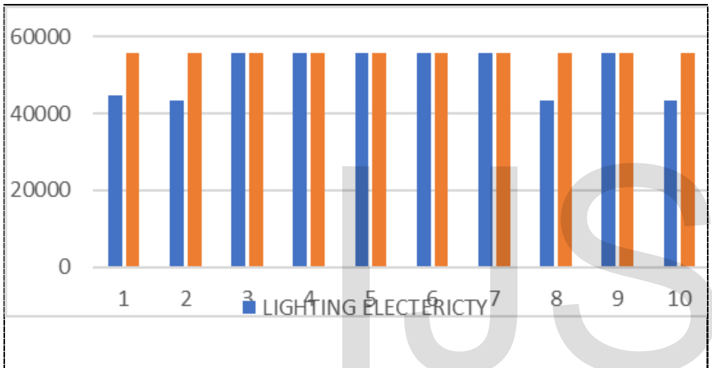


Fig.15 Heat generation comparison.

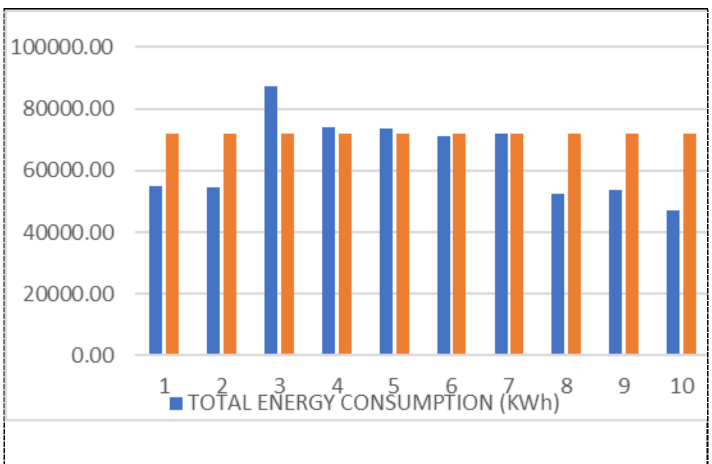


Fig.16 Total energy consumption comparison.

Fig.16. The efficient scenario in total energy consumption saving was Sn. 10 which minimize to 34.43% from the base case, generally Sn. 02, 02, 08, 09, 10 the more effective in energy consumption with ratio between 23.78 to 34.43% with Sn. 10(the more effective in energy consumption).

## 8 Conclusions

While low energy solutions for building become more popular day by day, architectural decisions used to reduce energy consumption. This research focused on some of those strategies for low energy building solutions and tested them in various scenarios by using DB software. It can be said that the architectural low energy solution has a noteworthy impact on total energy consumption, as seen from the results, using the selected strategies has saved 34.43% from total energy, 22.26% from lighting electricity, 33.85% from external ventilation. It advised that architectural low energy solutions should be the main way to energy reduction in buildings.

## References

[1] Reddy, B. Sudhakara, et al. Energy efficiency and climate change: conserving power for a sustainable future. SAGE Publications India, 2010.

[2] EEHC (2019a), Egyptian Electricity Holding Company Annual Report 2018/19; EEHC (2015), Egyptian Electricity Holding Company Annual Report 2018/19.

[3] Laila Amer Hashem Al-Qahtani, Lamis Saad Eldeen Elgizawi."Building envelope and energy saving case study: a residential building in AlRiyadh, Saudi Arabia", International Journal of Low-Carbon Technologies, 2020

[4] Attia, Shady. Net Zero Energy Buildings (NZEB): Concepts, frameworks and roadmap for project analysis and implementation. Butterworth-Heinemann, 2018.

[5] Kim, Jin-Hee, Ha-Ryeon Kim, and Jun-Tae Kim. "Analysis of photovoltaic applications in zero energy building cases of IEA SHC/EBC task 40/annex 52." Sustainability 7.7 (2015): 8782-8800.

[6] Marszal, J., and P. Heiselberg. "Zero Energy Building definition–a literature review (a technical report of subtask A)." Task40/Annex52 (2012): 1-16.

[7] Mirrahimi, Seyedehzahra, et al. "The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate." Renewable and Sustainable Energy Reviews 53 (2016): 1508-1519.

[8] Tallberg, Martin, and R. Bohne. "BIM based iterative simulation-efficient building design: a case study." IOP Conference Series: Earth and Environmental Science. Vol. 323. No. 1. IOP Publishing, 2019.

[9] Odonkor, Philip. Towards Net-zero Energy Building Clusters-Designing Operational Strategies for Optimal Energy Management. Diss. State University of New York at Buffalo, 2019.

[10] Inusa, Muktar, and Halil Zafer Alibaba. "Application of Passive Cooling Techniques in Residential Buildings; A Case Study of Northern Nigeria." International Journal of Engineering Research and Application 7.1 (2017): 22-30.

[11] Shamseldin, Amal Kamal Mohamed. "Compatibility of global environmental assessment methods of buildings with an Egyptian energy code." HBRC journal 13.1 (2017): 72-82.

[12] Hilliaho, Kimmo. "Energy Saving Potential and Interior Temperatures of Glazed Spaces: Evaluation through Measurements and Simulations." (2017).

[13] Eastman, Charles M., et al. BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors. John Wiley & Sons, 2011.