Effect of Pv Shadow on Cooling Load and Energy Consumption of Zone Toward Achieving NZEB

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Abstract. Development strategy offers us the resources required to investigate the connection between today's environmental challenges and the possibility of their progress tomorrow. Currently, the world is facing the greatest surge of population expansion in modern history, which forced governments to expand urbanization and establishing new cities to accommodate the massive population increase. As a result, the building sector's CO2 emissions have proceeded to grow by almost 1% a year since 2010. So there is an urgent need to find untraditional solutions to overcome upcoming energy, emissions problems and facing the expected increase of electricity prices. Nearly zero-energy buildings (NZEB) is one of the emerging technologies in the building sector which depend on enhancing building's energy performance and its extremely low energy demand is met with aid of renewable energy sources as PV solar panels. Via a study made on a conditioned zone located on the last floor of a university building belonging to Arab academy located in Alexandria, Egypt. The effect of the shadow caused by PV panels placed on the roof was studied. A 3D model of the zone was built, then a CFD analysis using the K-epsilon turbulence model was carried out to realize the essence of the shadow effect on this zone. For further clarity and using the DesignBuilder simulation tool the zone cooling load was calculated for both cases with and without PV on the roof, it was found that the zone cooling load reduced by 11.5% in case PV panels are installed on the roof.

Nomenclature

| NZEB | Nearly Zero energy building | ε | Turbulent dissipation rate |
|------|-----------------------------|---|---------------------------|
| λ    | Thermal conductivity of air | Pk | Shear production term in k-equation |
| Pr_t | Turbulent prandtl number | Pb | Buoyant production term in k-equation |
| U_i  | Average velocity | C_{ε1} | k_ε model constant |
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(U_j S_{Mj}) \quad \text{Work due to external momentum} \\
\tau_{ij} \quad \text{Viscous stress tensor} \\
C_{\varepsilon 2} \quad \text{k – \varepsilon model constant} \\
U \quad \text{Overall heat transfer coefficient}
\]

1. Introduction
What we are seeing today, in terms of the struggle of countries to keep up with growth and economic development by the use of fossil fuels, is oblivious to the severe implications that cannot be ignored in terms of altering the composition of the global environment. Requires a pause to reflect on the value of relying on renewable energy in various fields to achieve a concept of sustainability [1]. So the gap between economic expansion and the environment must also be reconciled to achieve the main objective of maintaining a prosperous economy through depending on clean energy resources. Climate change caused by exposure of greenhouse gas emissions into the atmosphere is one of the biggest challenges that arise [2].

The building sector is one of the major energy users responsible for 40% of energy-related emissions globally[3], the reduction of energy consumption in the building sector has encouraged the spread of the NZEB. A nearly zero-energy building is a building with extremely high energy efficiency and with almost zero or very low energy requirements, Building energy requirements are provided from renewable sources, including renewable energy from on-site or nearby sources [4][5]. According to the EPBD, The concept is based on two major aspects: the first is energy-savings and the second is renewable energy generation. Saving energy usually equals saving money, Mekkawi and Elgendy [6] achieved a 38% reduction in total energy consumption through changing the design parameters of a two-story housing prototype toward reaching NZEB using the DesignBuilder simulation tool. Moreover, a study was made on university buildings in reunion island, it is found that the energy consumption could be third of existing building consumption with only 2% additional cost with the aid of building simulation tools as reported by Garde et al. [7]. Therefore, there is an urgent need to convert many conventional buildings to NZEB to reduce energy usage to contribute to Egypt’s 2030 strategic plan [8].

To achieve NZEB, PV is required to provide a minimum of 30% of energy supplies [9]. The importance of using solar panels should not cease to be a source of green energy to satisfy the building’s need for electricity only to achieve the NZEB goal, but there is another importance to the shading caused by the solar panels that work to reduce the surface temperature and the consequent decrease in building energy consumption [10].

2. Methodology
With the aid of CFD and DesignBuilder simulation tools to predict the effect of the shadow caused by photovoltaic cells fixed on the roof on energy consumption of a conditioned zone on the last floor of Arab Academy for Science, Technology and Maritime Transport university building.
A fluid domain (zone) of 7, 10 and 3.10 meters long along the x-axis, y-axis, and z-axis respectively is used as a boundary condition -this zone is surrounded by conditioned zones- taking into account inlet and outlet openings are at 2.90 meters high from the floor to study the effect of this shading caused by PV on the zone. Then CFD analysis of a 3D model of the zone using energy equation (equation 1) and K-epsilon turbulence (equations 2 and 3) model for four scenarios (noPV,1PV,2PV,3PV) has been drawn using Designmodeller, a suitable mesh has been done for accurate results, input temperatures shown in table (1) were measured in the shade shown in figure (1a) and under direct sunlight as shown in figures (1b and 1c) with the aid of temperature, humidity and pressure sensor as shown in figure (1) on 25-10-2020.
Then this zone has been modeled using DesignBuilder through developing an ASHRAE baseline model of the zone using ASHRAE standards for the four cases no PV, one PV, Two PV, and three PV on the roof using DesignBuilder and using ASHRAE climatic conditions for Alexandria as shown in table (2). To compute the reduction in both cooling load and energy consumption due to the shadow of PV installed on the roof using the U-value of the roof reported by William et al. [11] in their research. Finally, the results of 4 models have been compared with each other.

| Table 1. Input data into simulation software |
|--------------------------------------------------|
| Roof Temperatures ºC | 33.1 |
| The temperature under PV ºC | 27 |
| U-value of the roof W/m² ºC [11] | 2.27 |

| Table 2. ASHRAE Design conditions for Alexandria [12] |
|--------------------------------------------------|
| DBT ºC | 33.2 |
| WBT ºC | 22.4 |
3. Results and discussion

3.1 CFD analysis outputs.

![Figure 2. Temperatures contours of roof and z-plane for 4 cases (fig (a) no PV, fig(b) 1PV, fig(c) 2PV, fig (d) 3PV)]](image)

By having four simulations for four cases (no PV, 1pv, 2pv, 3pv) to clarify the influence of PV shadow on the zone energy consumption, with the constancy of all other variables and through CFD analysis, temperature contours of four models computed as shown in figure (2), figure (2-a) show the temperature contour when no PV is installed on the roof the temperature of the air inside the room at plane z was 23.611 °C by adding one PV figure (2-b) on the roof and due to the shadow caused by it on the roof, the air temperature at plane z has been decreased to 23.32926 °C. And with adding another PV as shown in figure (2-c) the temperature continued decreasing until the temperature reached 23.312 °C, finally and after adding another PV as shown in figure (2-d) the temperature at plane z showed figure (3) dropped to 23.230 °C, which represents a reduced percentage of 1.61 % compared to no PV model.

![Figure 3. Temperature at Z-plane for 4 cases](image)

![Figure 4. Temperature contour of plane Z (3 PV on the roof)](image)
It was concluded that the net temperature of the roof has been decreased and the greater the surface area of the solar cells (PV), the lower the room temperature measured as shown in fig (3) at plane z=1.4, the temperature has been decreased from 23.611 °C (no PV model) to 23.230 °C as shown in figure (4). After knowing the effect of PV on zone temperature and for further analysis these four models have been simulated using DesignBuilder to predict the effect of PV shadow on zone energy consumption.

3.2 Design builder results

Through running the four cases (figure 5) to show the effect of PV shadow on the roof and its impact on zone cooling load and energy consumption.

![3D models from DesignBuilder simulation tool](image)

**Figure 5.** 3D models from DesignBuilder simulation tool

![Cooling Capacity and Annual Energy Consumption](image)

**Figure 6.** Effect of shadow on zone cooling capacity

**Figure 7.** Annual energy consumption of the zone for 4 models

As shown in the figures (6 and 7), and through simulating 4 Models using DesignBuilder to predict the effect of the PV shadow on Zone cooling load and energy consumption, it was concluded that the cooling load decreases as the number of solar cells increases, as there was a reduction of 11.5% comparing no PV with three PV on the roof of the zone case, causing a decrease in the rate of energy...
consumption by 7.03% comparing between no PV and 3PV models, according to updated prices of electricity and due to the shading caused by PV on the roof of this zone, 2083.536 LE could be saved annually from this zone, Although the small temperature difference caused by the shadow on the zone roof as showed in figure (8).

4. Conclusion
This study showed that the importance of PV is not only for the generation of electricity for buildings particularly if the goal is to reach NZEB, but also the shading effect that contributes to the reduction of the energy consumption of buildings towards reaching NZEB, Through simulation tools the effect of PV shadow on the zone in the educational building in Alexandria was studied. It was found that the temperature of the zone decreased due to the shadow of PV causing a reduction of 11.05% in the cooling load. This reduction led to a 7.03% decrease in the annual energy consumption of the zone.

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Figure 8. Zone air temperature for both cases (no PV, 3pv)
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