Cooling down roof mounted solar panels by optimizing the natural air movement around them

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Abstract. Weather circumstances, such as wind, temperature, and dust storms, can be considered as major factors that have a significant impact on the performance of solar panels. Iraq has been chosen in this study to examine the solar panels performance because of its rough and variable weather conditions around the year. For instance, Iraq has a long summer which lasts for six months, with a high sun radiation and an ambient temperature that rises to 50 °C (122 °F) in shade. Moreover, sun radiation in winter remains at high levels due to the low cloud cover. High temperature is the most challenging problems effecting the efficiency of solar panels in Iraq. Solar panels cells are highly sensitive to the temperature, the higher the temperature of the solar cells, the lower the outcome performance. In this research, the impact of the gap size between solar panels and the rooftop on the air movement velocity is examined. The temperature below solar panels is also measured. Computer simulation method is adopted in this research. Two solar panel designs with various rises are tested on a typical house roof in Iraq. It was found that the gap size between the solar panels and the rooftop in addition to their distribution on the roof have an impact on the air velocity around the solar panels, hence on their temperature. Furthermore, Solar panels performance can be improved by adjusting the rise of the solar panels.

1. Introduction
Solar panels or photovoltaic panels (PV) performance can be effected by the weather conditions in specific areas, such as ambient temperature, soiling, sun irradiation and wind speed. Dust storms is one of the most challenging problems that is limiting the use of solar panels as an alternative power resource in Iraq. Soiling affects the performance of solar panels as it decreases the power output of solar panels by increasing the reflections in the atmosphere, and subsequently reduce the solar irradiance that reaches the PV cells. Dust accumulation on the surface of the PV panels can reduce the amount of solar radiation that reaches the solar cells. Studies about the effect of the dust accumulation on the PV panels have quantified that value of the efficiency reduction is 15%. [1]. A study in Mesa, Arizona which has a considerable similarity in climate condition to that in Baghdad, Iraq, aimed to quantify the effect of soiling on the performance of the PV panels and find the relationship between the PV panels tilt angle and the amount of the dust accumulation on its surface [2]. That study contained two sets of PV panels, each set had 9 PV panels. The first set kept clean while the other set was left exposed to the natural dust accumulation. The 9 PV panels on each set have been examined in different angles: 0°, 5°, 10°, 15°, 20°, 23°, 30°, 33° and 40°. The output power of each module, the module temperature, and the irradiance were measured each two minutes for three months (from January to March 2011). The researchers have indicated that the insolation loss and the soiling effect increases with the decrease of the tilt angles mentioned earlier. PV panels temperature has a significant effect on their performance. PV cells temperature depends on the ambient temperature, wind speed and the
amount of the solar irradiance. Also it is found that the performance of the PV panels decreases 0.5%/°C when the PV module temperature increases above 25 °C (77 °F) [3].

A study in South Greek examined the effect of the wind on the temperature of the PV panel’s surface. This study analysed the data of two PV systems. The first system is a building-integrated PV system facing south at Chania of Crete, with polycrystalline panels located on the roof of an industrial building in a tilt angle of 12°. This system has been designed to be operated at average temperature of 35 °C (95 °F), while it has been found that the actual temperature in this system reached 70° C (158° F). This significant rise in the PV temperature attributed to the integrated PV system which prevents the natural cooling by the wind movement behind the panels. However, the integrated system has benefits such as low cost and small area requirements to install the PV panels. The second system was installed in a farm with no shading. This system installed in a 30 degree tilt angle consisting of 586 polycrystalline panels, each row had 20 modules and the distance between rows is 8.5 m (27.88 ft). This system, located in Ligourio (Argolida), operates in an average temperature of 27° C (80.6° F), while the actual PV temperature reached 60° C (140° F). Ambient temperature, PV temperature, solar irradiance, wind speed, and output power have been calculated from both systems along an entire year (April 2010 to March 2011). Chania system witnessed an annual wind speed average of 0.4 m/s (1.3 ft/s) while the Ligourio system witnessed an annual wind speed average of 1.6 m/s (5.2 ft/s). Due to the low wind speed in the Chania System, the thermal loss increases and the efficiency of the PV panels decreases due the rise of the PV cells temperature. It was found that the difference between the PV cells temperature and the ambient temperature decreases with the increase of the wind speed. In this study, it was found that the Ligouria average difference between the ambient and the PV cell temperature is 14° C (25.2° F), while the difference in the Chania system is 25° C (45°F). For the Ligourio system, the temperature coefficient is estimated to be around 0.30%/°C, while it is about 0.44%/°C for the Chania system. [4]

Another study in Iraq in three cities: Baghdad in the middle, Mosul in the north, and Basrah in the south. A system of 57500 PV panels generates 5 MW and additional 1 MW from 100 wind turbines have been installed in each city. The aims were to calculate the output power and to compare the result of the three cities and discover what is the perfect place to obtain the higher efficiency. This system was designed to meet the need of 750 houses in remote areas with an average power consumption of 30 KW/day per house. The area that needed for this system is 40m x 400m (131ft x1312ft). The input data that have been calculated from those three locations are solar irradiation, ambient temperature and wind speed. The output power has been measured for the three systems to compare the results. It was found that the solar irradiation in Basrah is the highest while it was the lowest in Baghdad, and subsequently Basrah has the highest output power along the year with an annual total power of 8500 MWh, Mosul comes in the second place with 8300 MWh, while Baghdad has about 7400 MWh. [5]

2. Methodology
A computer simulation of airflow and heat distribution around solar panels installed on the roof of a typical house in Iraq is the method that was adopted in this research. Visualizing air flow (floVent) software was used to analyze air movement and temperature around the solar panels.

2.1. Model setup
A typical house in Iraq was modelled first (two-storey house facing south) and an array of solar panels was installed on the available roof area of the house. Solar panels array was fixed 0.6 m above the roof surface with a tilt angle of 25 degree facing south (to collect the maximum sun radiation) as shown in figure1. The ambient temperature was chosen to be 33° C (91.4° F) as the average temperature in Iraq while the wind speed was chosen to be 8 m/sec (26.24 ft/sec). figure 2 represents the average temperature in Iraq in 2018. [6]
2.2. Monitoring procedure
To test the air movement around solar panels array, the prevailing wind in Iraq (north-westerly wind) was considered in this research in addition to the southerly wind—which is perpendicular to the solar panels surface. The two types of wind were tested on the model to show their effect on cooling down the solar panels and improving their performance.

To measure the roof temperature, three monitor points were located under the solar panels on the roof (monitor point 1, 2, and 3) as shown in figure 3.

Figure 1. A model of a typical house in Iraq with a solar panels array mounted on the roof.

Figure 2. Average temperature in Baghdad-Iraq [6].

Figure 3. Monitor point locations on the roof.
2.3. Testing procedure
First step was testing the solar panels by changing the solar panels layout and wind direction. Reinforced concrete was set as the roof material and glass was set as the solar panels material:

2.3.1. First solar panels layout with north-westerly wind
As described above in 2.1, a typical two-storey house in Iraq was modelled and tested with a north-westerly wind using small pieces of solar panels mounted individually on the roof. They rise 0.6 m (1.96 ft) above the roof.

2.3.2. First solar panels layout with southerly wind
The model described in 2.3.1 was installed, but tested with a southerly wind that blows perpendicular to the solar panels surface.

2.3.3. Second solar panels layout with north-westerly wind
In this layout, solar panels were installed in groups instead of installing them individually. This layout creates larger pieces of solar panels with larger spaces between them (the same surface area of solar panels was used to generate the same amount of energy). This model was tested with a north-westerly wind.

2.3.4. Second solar panels layout with southerly wind
The solar panels layout described in 2.3.3 was installed and tested with a southerly wind.

2.3.5. Changing the rise of solar array
The second step of this research was testing various rises of solar panels above the roof, starting from 5 cm (2 in.) above the roof surface reaching 1.5 m (4.9 in.). This test showed the effect of increasing the rise of solar panels on the air velocity below solar panels array and hence, on cooling them down.

3. Results and discussion

3.1. First layout with north-westerly wind
Since solar panels were located to face south in order to obtain the maximum possible amount of sun radiation, the north-southerly wind blows almost parallel to the solar panels. In this case the stair house, which is an element that exists in every Iraqi house, works as a barrier that prevents the air from flowing under the PV panels that are located behind it. Otherwise the wind flows smoothly around the PV panels on other locations. Figure 4 shows wind velocity around solar panels measured in ft/s where the scale ranges from 0 to 44 ft/s (0 to 13.4 m/s).

Regarding roof temperature, it is higher behind the stair house than other locations. The stair house prevents the wind from cooling the space behind it. The temperature also rises under the PV panels since the panels were heated by the sun heat, and the air movement around them is not sufficient to cool them down. Figure 5 shows air temperature on the roof under the solar panels array measured in Celsius degree and the scale ranges from 20 to 45+ C (68 to 113+ F).
Figure 6 is a section through the roof and shows that the air velocity is 0 ft/s (0 m/s) behind the stair house. The air velocity rises in other locations to reach 13 ft/s (3.9 m/s) where no barriers blocking the wind flow. On the other hand, figure 7 shows that the temperature under the solar panels behind the stair house rises to 40º C (104 ºF), while in other locations, the temperature was lower by 3º to 4º C (5.4 to 7.2º F).

Figure 8 shows the results of the three monitor points that were located on the roof to measure the surface temperature. The graph shows that monitor point number 2 which was located behind stair house has the highest reading. Monitor point number 2 is 4º C (7.2º F) higher than the other two points.

Figure 7. Section through the roof behind stair house shows air temperature under the solar panels.

Figure 8. A graph shows the temperature variation between the three monitoring points of the first layout with north-westerly wind.

3.2. First layout with southerly wind
After testing the prevailing wind in Iraq (North-westerly wind), the southerly wind, which is perpendicular to the solar panels surface, was tested on the same solar panels layout with the same material properties. With the wind blowing from south, the stair house has no effect on the air movement. The wind collides with the solar panels and shove its way over and under them. As shown in figures 9 and 10, air speed is low below the solar panels reaching 0 ft/s (0m/s). Figures 11 and 12 show that the temperature is higher under the PV panels.
Monitor point number 1 shows in figure 13 an increase in temperature compared to the other two points. That can be related to the rear parapet of the roof that blocks the wind. It creates a zone where solar panels are gradually heated by the sun without a sufficient air movement to cool them down.

Figure 9. Plan of the roof shows air velocity around solar panels.

Figure 10. Section through the roof shows air velocity around solar panels.

Figure 11. Plan of the roof shows air temperature around solar panels.

Figure 12. Section through the roof shows air temperature under solar panels.

Figure 13. A graph shows the temperature variation between the three monitor points of the first layout with southerly wind.
3.3. Second solar panels layout with north-westerly wind

Another layout was suggested as an attempt to improve air movement around solar panels as shown in figure 14. The new layout was designed to provide larger spaces between the solar panels pieces. Providing larger spaces might ease the movement of the air around the PV panels and reduce the temperature of the roof and the PV panels. (North-westerly wind solar panels rise 0.6 m above the roof).

![Figure 14](image1.png)

**Figure 14.** A roof plan shows the air velocity around the second layout of solar panels with a north-westerly wind.

![Figure 15](image2.png)

**Figure 15.** A section through the roof shows the air velocity under the second layout of solar panels with a north-westerly wind.

Figures 14 and 15 show that the air velocity behind stair house is still lower than other locations on the roof while the temperature is higher than other locations as shown in figure 16. The temperature under the solar panels was dropped compared to the first layout as shown in figure 17.

Figure 18 shows that the temperature of the three monitor points on the roof having a more consistent reading than the first layout with a temperature of about 36º C (96.8 º F).

![Figure 16](image3.png)

**Figure 16.** A roof plan shows surface temperature of the second layout of solar panels with a north-westerly wind.

![Figure 17](image4.png)

**Figure 17.** A section through the roof shows the temperature under the second layout of solar panels with a north-westerly wind.

Figures 19, 20, and 21 represent a comparison of the temperature of the three monitoring points in the first and second layout of the solar panels. The results show that for monitor point number 1 the temperature was consistent in both layouts. In the second monitor point, which is behind the stair house, the results show a reduction in temperature in the second layout by about 4º C (7.2 º F) compared to the first layout. The third monitor point showed a slight increase in temperature by about 1º C (1.8 º F) in the second layout.
3.4. Second solar panels layout with southerly wind

![Graph showing temperature of monitor points 1, 2, and 3 with southerly wind](image1.png)

**Figure 18.** A graph shows a more consistent temperature of the three monitoring points of the second layout with a north-westerly wind.

![Graph showing temperature of monitor point 1 with southerly wind](image2.png)

**Figure 19.** Monitor point 1 reading in the first and second layout with a north-westerly wind.

![Graph showing temperature of monitor point 2 with southerly wind](image3.png)

**Figure 20.** Monitor point 2 reading in the first and second layout with a north-westerly wind.

![Graph showing temperature of monitor point 3 with southerly wind](image4.png)

**Figure 21.** Monitor point 3 reading in the first and second layout with a north-westerly wind.

The second solar panels layout was tested with the southerly wind which is perpendicular to the solar panels. The results show that air temperature under the solar panels is higher than other locations because air movement under them was not sufficient to cool the panels down after they were heated by the sun as illustrated in figures 22, and 23.
southerly wind.

monitoring points

Figure 24

while they were gradually heated by the sun wind. That creates a zone with a wind movement that is not enough to cool the solar panels down due to the location of the last row of solar panels which is close to the rear parapet which blocks the wind. That creates a zone with a wind movement that is not enough to cool the solar panels down while they were gradually heated by the sun as shown in figure 24.

The results also show an increase in the temperature of monitoring point number 1. That may be due to the location of the last row of solar panels which is close to the rear parapet which blocks the wind. That creates a zone with a wind movement that is not enough to cool the solar panels down while they were gradually heated by the sun as shown in figure 24.

Figure 22. Air temperature below and around solar panels for the second layout with a southerly wind a) roof plan b) section through the roof.

Figure 23. Air velocity below and around solar panels for the second layout with a southerly wind a) roof plan b) section through the roof.

Figure 24. Temperature variation of the three monitoring points of the second layout with a southerly wind.

Figure 25. Monitor point 1 reading of the first and second layout with a southerly wind.

Figure 26. Monitor point 2 reading of the first and second layout with a southerly wind.

Figure 27. Monitor point 3 reading of the first and second layout with a southerly wind.
Figures 25, 26, and 27 represent a comparison of the three monitor points between the first and second design with a southerly wind. The results show that the temperature in the second solar panels layout is higher than the first layout in monitor points 1 and 3, while monitor point 2 had the same temperature in both layouts. Bigger pieces of solar panels block the southerly wind more than the smaller pieces and result in a higher temperature under the solar panels.

3.5. Changing the rise of solar array

After testing the effect of changing the solar panels layout design on the velocity of air movement around them, the solar panels were tested in various heights above the roof. The solar panels were installed 5 cm, 0.6 m, 1 m, and 1.5 m (0.16 ft, 1.96 ft, 3.2 ft, and 4.9 ft.) above the roof with a southerly wind. The results show that increasing the rise of the solar panels from 5 cm (0.16 ft) to 1.5 m (4.9 ft) increased the air velocity from 0 ft/s (90m/s) to 17.6 ft/s (5.4m/s) and reduced the temperature from 42°C (107°F) to 32°C (89.6°F).

![Solar panels installed in various rises above roof](image)

**Figure 28.** Solar panels installed in various rises above roof

4. Conclusion

This paper aims to optimize the air flow and air temperature around and below solar panels array that are installed on the roof of a typical house in Iraq. From this research it was concluded that:

- Northwesterly wind flew smoothly under the PV panels since it blows parallel to them. However, the stair house works as a barrier that blocks the wind and prevent the air to flow under the PV panels that are located behind it.
- Southerly wind is perpendicular to the PV panels and the stair house has no effect on the air movement. Since the air blows perpendicularly to the solar panels, the wind collides on the solar panels surface and distribute over and under them, thus the solar panels in this case blocks the wind and reduce its velocity.
- Bigger pieces of solar panels with larger spaces between them ease the movement of the Northwesterly wind and provide better ventilation and subsequently lower temperature and better performance for the PV panels. However, when the wind blows from south, the temperature increases because the wind is perpendicular to the solar panels and the panels works as barriers that blocks the wind and reduce its velocity.
• Higher distance between the PV panels and the roof leads to a faster air movement. Rising the PV panels over the roof enables the wind to blow faster under them and decreases the temperature of the roof and the PV panels.

5. References
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