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Impact of Rooftop PV Shading on Net Electrical Energy Demand of Buildings in Pakistan

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ABSTRACT

This work performs a quantitative assessment of the impact of rooftop PV installation on building's net energy demand using model of roof structure and steady state thermal simulations. For this purpose, roof structure typically used in Faisalabad, Pakistan is modeled with and without the shading effect due to a 395 W commercial rooftop PV setup. The simulated parameters include the impact of PV module's dimensions, mounting position/angle alongside roof size and ambient conditions on heat load of air-conditioning system to maintain a temperature of 25 °C within building's top floor. During the daylight hours of July, the heat load added by the roof on average reduces from 150.87 BTU/h/m^2 without PV to 118.16 BTU/h/m^2 with PV structure. This 20.05% reduction in energy demand has been achieved with July's maximum daytime solar and infrared irradiances of 792.2 W/m^2 and 466 W/m^2 recorded at an average ambient temperature of 35.5 °C and wind speed of 2.75 m/s. This study provides valuable data on optimization of roof layer structure during building's construction in anticipation of PV system installation at a later stage. Also developed techniques/methods to reduce building's energy budget due to PV installation, can be valuable input for construction industry as well.

Keywords: *Photovoltaic, Thermal Simulation, Roof Model, Rooftop PV, Energy budget, System Model, PV Model, Simulation*

RESEARCH HIGHLIGHTS

1. This work aims at quantitative assessment of impact of rooftop PV shading on net electrical energy demand of buildings in semi-arid regions of Pakistan.
2. Thermal steady state simulations of roof structure with and without PV system are performed for the ambient conditions available in Faisalabad, Pakistan for the month of July.
3. A maximum of 27.79% reduction in heat flux magnitude through roof structure from 200.79 BTU/h/m^2 to 144.98 BTU/h/m^2 is expected due to shading effect to maintain a temperature of 25°C within the building.
4. This study can help guide consumers and policy makers to reduce electrical energy demand.

Research Objectives

The semi-arid regions of Pakistan with their large solar irradiance levels provides ideal locations to build large scale solar farms. Furthermore, the availability of huge lakes and dams in such regions also show potential of floating PV systems (1,2). However, a significant portion of electricity demand in Pakistan and worldwide, stems from heating, ventilation and air-conditioning (HVAC) requirements of buildings in residential (3) and commercial areas where on-site small scale solar systems can help avoid distribution system losses. In such locations, Roof structures directly face the sun throughout the day and are a major source of heat capture in buildings (4). Rooftop PV systems, installed primarily to reduce dependence on National Grid and electricity cost, can also lower HVAC requirements due to shading effect of the rooftop PV systems (5). This work aims at quantitative assessment of impact of rooftop PV shading on net electrical energy demand of buildings in semi-arid regions of Pakistan. Proper modelling of rooftop PV's shading effect can provide a more accurate analysis of payback period of rooftop PV systems as well. This study can help guide consumers and policy makers to reduce electrical energy demand.

Methodology

Applicability of multi-physics software for analyzing PV system and it's thermal effect on roof top slab under different parameters is used. For this purpose, roof structure's dimensions alongside PV module's dimensions, orientation and electrical parameters are modeled in Multi-Physics simulation software based on material properties and parameter values available in literature and datasheets. Considered environmental parameters are wind speed, ambient temperature, building's inside temperature, short wave solar irradiance and incident long wave infrared radiation for the month of July in Faisalabad, Pakistan. Performed steady state thermal simulations consider heat transfer due to conduction, convection, solar irradiance and infrared radiation.

Simulations are performed with and without PV module to compare heat energy transferred to building via the roof to maintain 25° C air temperature inside building. The net heat flow through the roof in both scenarios depicts the amount of heat load that the air conditioning system must remove to maintain fixed air temperature and corresponds to electrical energy consumed by the Air conditiong system. Comparison of the two heat loads corresponds to the impact of rooftop PV shading on electrical energy demand within the building.

Results

During the month of July, daytime solar and infrared irradiances of maximum 792.2 W/m^2 and 466 W/m^2 have been recorded for Faisalabad city. The average ambient temperature of the 24-hour day is 35.5 °C while the corresponding average wind speed is 2.75 m/s. Under these simulation settings, the heat load added by the roof on average reduces by 20.05% from 150.87 BTU/h/m^2 without PV to 118.16 BTU/h/m^2 with PV structure during the daylight hours of July. Here, a maximum of 27.79% reduction in heat flux magnitude from 200.78 BTU/m^2 to 144.98 BTU/m^2 has been achieved from 11 am to 12 pm due to shading effect.

Furthermore, a cumulative 16.48% reduction in heat flux magnitude is expected during the entire month of July once the rooftop is covered with PV system. This corresponds to a 16.48% reduction in roof based heat load for Air conditioning system and corresponds to similar reduction in electricity demand for HVAC.

Findings

An estimated 16.48% reduction in heat flux magnitude from roof is expected due to shading effect of rooftop PV system during July in semiarid urban areas of Faisalabad, Pakistan. However, a more thorough study considering impact of solar rooftop system for different months, roof structures and climates is needed.

Nonetheless, this study provides assistance to consumers, construction industry specialists and energy policy makers to comprehend the larger impact of solar rooftop mounting on energy demand in building/residential areas and to optimize roof construction materials specifically the ones related to Thermal insulation in anticipation of rooftop PV installation later on.

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