Variations in proximate temperatures due to Rooftop Solar PV heating: Simulation approach

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1. Introduction

Surface properties are critical to its interaction with the environment. Different materials have unique properties of reflecting, absorbing, and transmitting heat. Urban development can modify the geomorphology of the landscape, and alter the soil profiles, and the hydrology of the area. Millstein and Menon highlighted that variation in albedo, can change temperature by 60% (Millstein and Menon, 2011). This results in more heat absorption, radiation, and reflectance. In a less urbanized area, the surface absorbs certain part of the heat, and reflects the rest which gets dissipated in the atmosphere. Whereas, in a highly urbanised area, more heat is absorbed, and dissipation does not occur easily.

With determination to follow the ambitious target of Net Zero Emissions in the coming years by various countries this renewable energy technology has shown promising results. First generation SPV, also known as the silicon-based PV technology, is predominantly being used in most parts of the globe. The fundamental reason is that by far it is the most mature, stable, and affordable technology in comparison to the other next generation PV technologies. However, mentioned merits come at a price of least flexibility towards its integration into the buildings, making it a dotting solution over the rooftops and several other hard surfaces. As Photovoltaic (PV) panels increasingly become a part of the urban environment, they also alter this delicate balance of heat transfer. Scherba et al, and Genchi et al highlighted in their respective studies, the impact of PV panels is quite different in a cool roof (Genchi et al., 2003), and the roof surfaces with PV installation heat more (Scherba et al., 2011).

This paper examines the thermal impact of a PV module on and around three different types of installation surfaces with different material properties i.e., concrete, asphalt, and cool roof, while keeping the material properties of PV same in all three cases. The intent is to understand the variation in surface and near surface air temperature during summer and winter.

2. Methodology

The work presented here focuses on identifying the behavior of SPV installations on three different hard surface rooftops. Modelling of surface and near surface temperature on and around concrete, asphalt and cool roof surfaces with rooftop SPV installations in summer and winter seasons is done. The simulation results help in understanding the behavior of rooftop SPV installations on roofs with different surface properties (Table 1) in a composite climate of National Capital Territory (NCT) of New Delhi. Emphasis is on the simulation of the temperature variation on surfaces with different emissive and reflective properties.

A methodological simulation procedure (figure 1) using ambient data in the COMSOL Multiphysics modelling environment and spatial visualization of temperature profile is adopted. Results are then used to assess the heat flux variation on three different surfaces- asphalt, concrete, cool roof, in the same ambient thermal conditions. In the simulation model total six temperature data points are identified (figure 1).

Three points on the surfaces: SPV surface (Sim_T_{pv}), exposed roof surface (Sim_T_S_o) & surface shaded by SPV (Sim_T_s_c). Other three points are air temperature points placed above SPV at varying heights: Sim_Ta_1, Sim_Ta_2 and Sim_Ta_3 at 0.2 m, 1.2m, and 10m above SPV surface respectively.

Table 1: material properties

Description	Asphalt surface	Concrete surface	Cool roof surface
Dimensions (m) X; Y; Z	4, 6, 0.3	4, 6, 0.3	4, 6, 0.3
Thermal Conductivity W/ (m.K)	0.75	1.8	1.8
Specific Heat Capacity J/(kg.K)	920	880	1100
Emissivity	0.94	0.90	0.95
Reflectivity	0.16	0.4	0.52
Absorption coefficient	0.84	0.6	0.48

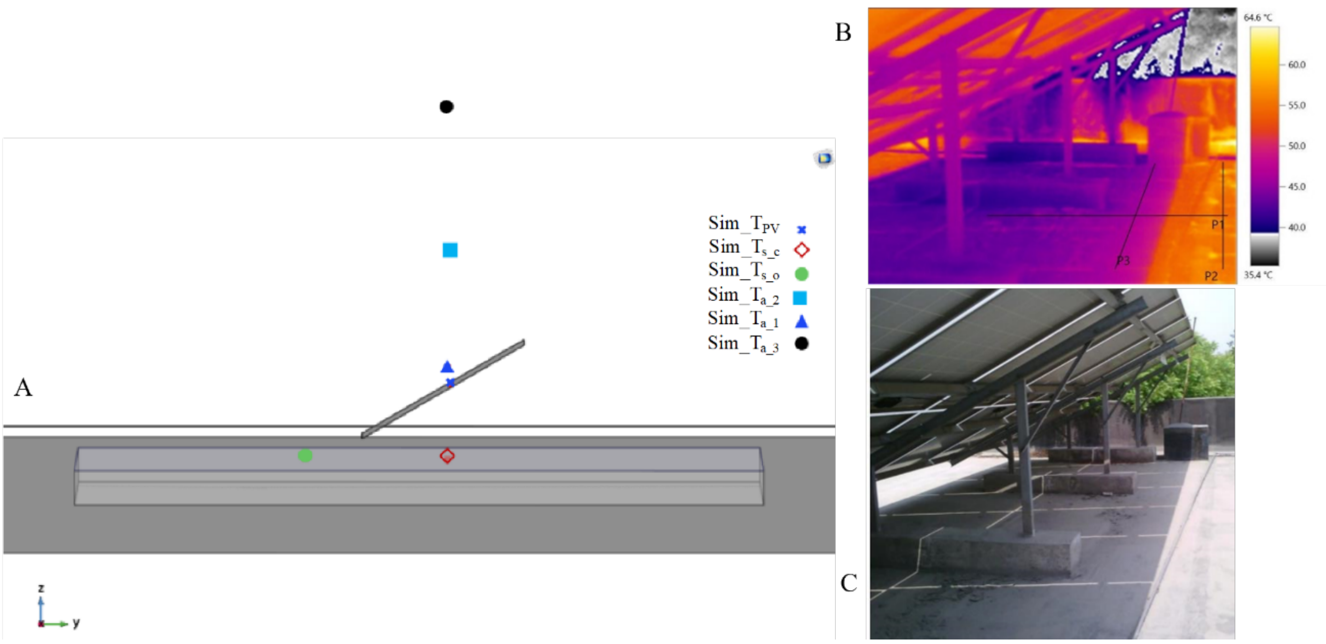

Figure 1. PV simulation model with temperature points

2.1 Modelling framework

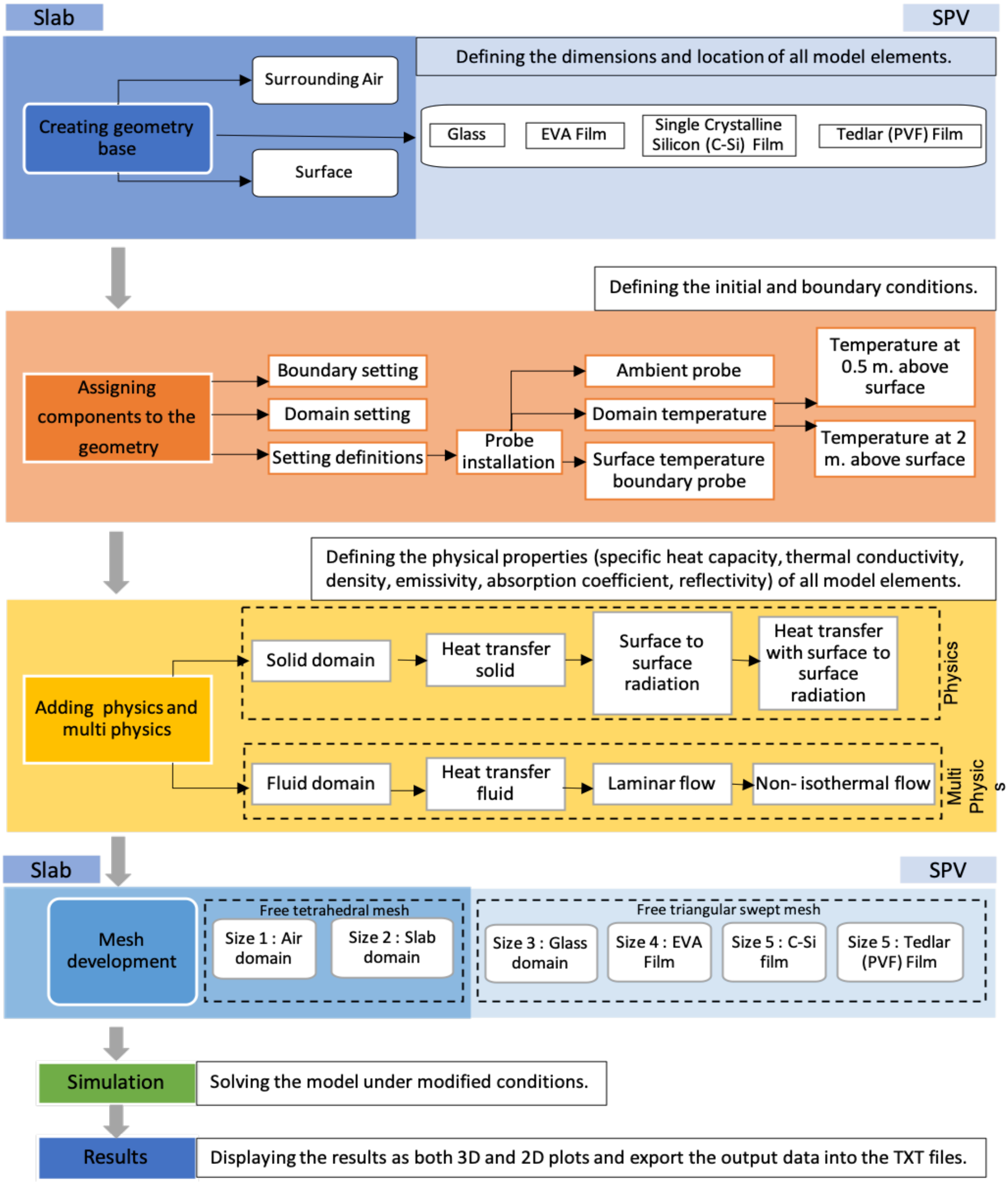

Figure 2: Modelling Framework

3. Inferences

The hourly mean temperature of SPV remains highest in case of cool roof and the lowest surface temperature is seen in case of asphalt roof (figure 3). The SPV surface temperature profile remains most in sync with the variation in solar insolation.

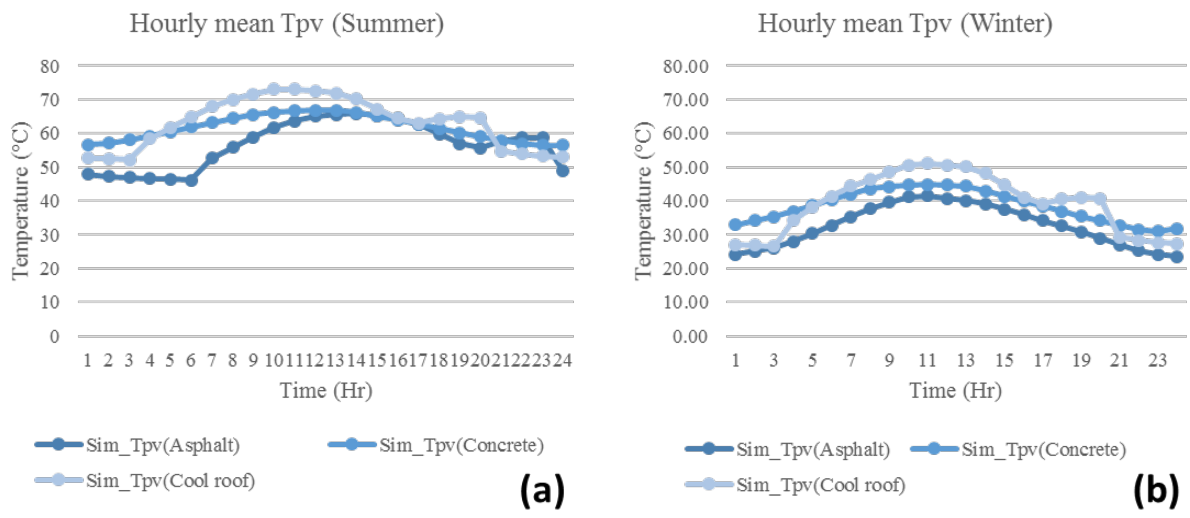

Figure 3: Hourly mean temperature of SPV (summer and winter)

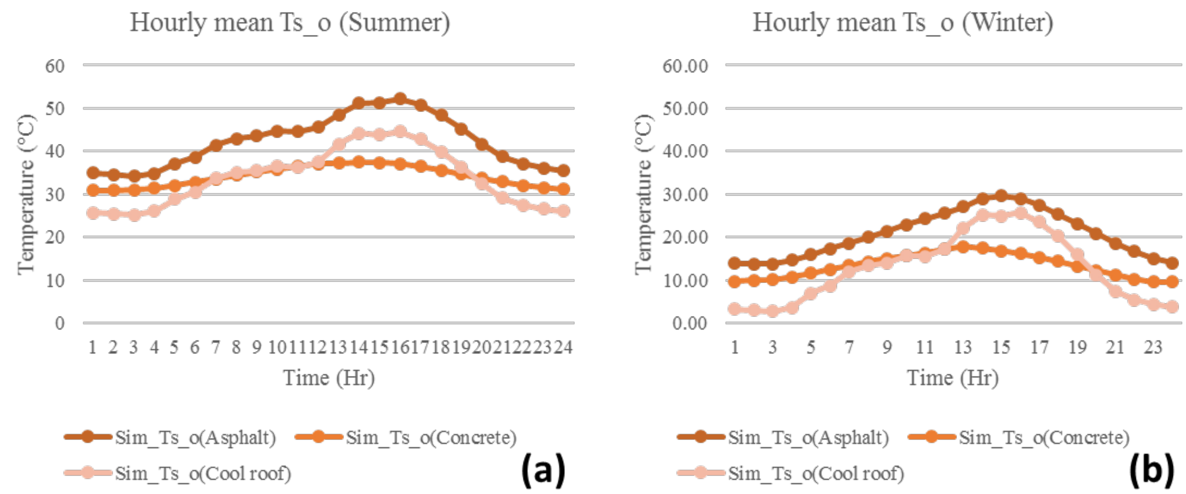

Figure 4: hourly mean temperature of open surface (summer and winter)

The hourly mean temperature of open surface (Ts_o) is the highest for asphalt and the temperature profile of asphalt is similar to the cool roof profile in summers with a minor variation in winter (figure 4). The hourly mean temperature profile of concrete remains most in sync with the variation in solar insolation showing a gradual increase and decrease.

The hourly mean temperature of covered surface (Ts_c) is the highest for asphalt and the temperature profile of asphalt is similar to the cool roof profile in summers (figure 5a). However, in winters the peak temperature value of cool roof goes slightly higher than the asphalt value (figure 5b). Additionally, the temperature profile of cool roof shows a rapid increase and decrease compared to the asphalt and concrete surface. The hourly mean temperature profile of concrete remains most in sync with the variation in solar insolation showing a gradual increase and decrease. Moreover, the Ts_c values for cool roof demonstrate a negative trend during nighttime.

The paper establishes that a cool roof performs most adversely with SPV installations as heat gets trapped underneath the SPV panels resulting in increased temperatures which negates the benefits of a cool roof. The hourly mean temperature (summers) of the SPV was found to be highest in cool roof with the maximum temperature of 71°C while the value was 68°C and 65°C for concrete and asphalt respectively. The concrete surface had the most stable trends with gradual increase and decrease for all measured temperature values in summers as well as winters.

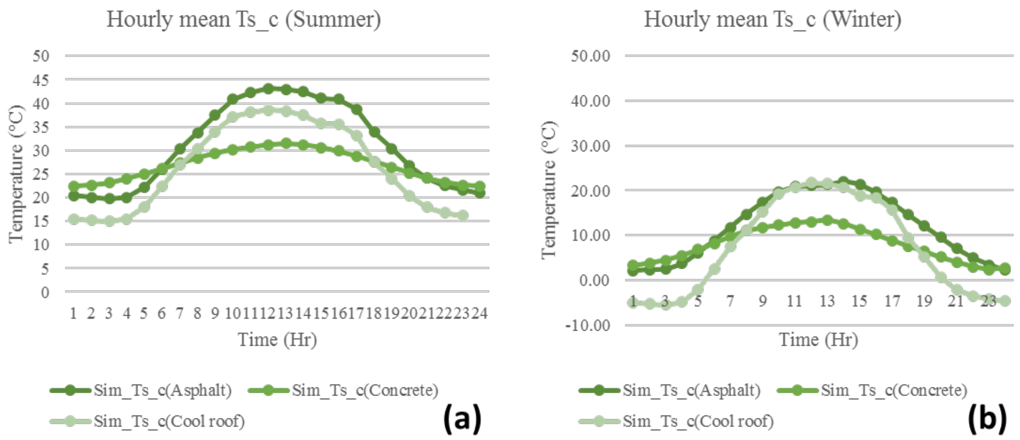

Figure 5: hourly mean temperature of covered surface (summer and winter)

4. Conclusion

Overall, from the data it is visible that low thermal mass and dark surface of PV having low albedo increases radiative forcing due to which the surface loses heat rapidly. Additionally, in all three cases, PV is affecting the surface temperature of open and covered surfaces in both studied seasons and vice versa.

The open surface temperatures of all three surface types increase as the day progresses i.e., increase in sun altitude; however, the temperature of cool roof surface is consistently lower than the asphalt roof surface. The most plausible reason for this occurrence is the high reflectivity of the cool roof surface. However, the temperature of concrete roof becomes lower than cool roof after 12 noon, which proves that PV influences the thermal behaviour of surrounding surfaces. It is observed that the low thermal mass and dark surface of SPV with its low albedo results in rapid heat loss.

In case of the covered surface temperatures, asphalt shows the highest values closely followed by cool roof, which substantiates the connection between surface reflectivity and heat trapping as more heat is trapped under the surface of the PV installed on a cool roof; thus, negating the benefit of having a cool roof. This paper concludes with the findings that reflectivity and emissivity of a material's surface have a strong influence on its surface temperature and near surface air temperature. Moreover, the research suggests the requirement of design based technical innovations for the use of this technology in the built fabric.

References

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