Techno-economic Analysis of Solar Photovoltaic Cooling System: an analysis in four different climates in India

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Abstract

This study covers the techno- economic analysis of solar energy based cooling system using photovoltaic (PV) technology for an office building located in four different climatic zones of India using simulation techniques. The building geometry, user profile and construction have been considered identical for chosen locations in four climatic zones; Ahmedabad from hot and dry zone, Bangalore from moderate zone , Chennai from warm and humid zone and Delhi from composite zone. The building modeling has been done using Googlesketch up software while the simulation has been carried using TRNSYS v-17 software. The cooling load of the building varies with the climatic zones. Technically solar photovoltaic cooling system is possible having the solar fraction in the range of 0.24-0.57 and Primary energy savings reaches 57 % in the hot and dry climate. In this way the carbon dioxide (CO_2) emission is also avoided. The payback periods, are higher in all the climate zones and the least being 14.23 years for the hot and dry climate. When PV based systems are optimally used with net metering provisions during the non cooling periods then the payback period is 4-6 years for all climate zones. On the basis of techno-economic analysis, it is recommended that considering the prevailing costs and performance levels, net metering scheme should be immediately introduced in all states.

1. Introduction

To improve the thermal comfort conditions, particularly in the summer season, there is growing demand of conventional vapour compression air conditioners. This growing demand not only increases electricity consumption but also global warming. Building architectural characteristics and trends like increasing ratio of transparent to opaque surfaces in the building envelope to even popular glass buildings has also significantly increased the thermal load on the air conditioners (Henning 2007).

The conventional vapour compression refrigeration cycle driven by grid electricity increases the real cost of development. Firstly, it strongly increases the consumption of electricity and fossil energy. Energy sources based on fossil fuels such as coal, oil, gas, and nuclear energy sources etc., are either diminishing or are scarce in nature, location and volume hence a serious energy deficiency threat. In addition it causes serious environmental hazards by releasing poisonous gases. One of the major environmental issues is acid rain resulting from sulphurous gases emitted from power plants, killing sensitive living species, disrupting complex soil chemistry and affecting human health. Green house gases such as CO_2 (by product of combustion of fossil fuels), CH_4, N_2O, and halocarbons released from human activities absorb outgoing energy from the earth and cause warming effects. Secondly, the refrigerants like chlorofluocarbures (CFCs), hydrochlorofluorocarbures (HCFCs) and hydrofluocarbues (HFCs) are also responsible for ozone depletion and global warming (Fan et al. 2007). In the present work parametric study and performance analysis of solar photovoltaic cooling systems has been performed considering the annual solar fraction and relative primary energy savings. For performance analysis, Ahmedabad represents hot and dry climate, Bangalore represents moderate climate, Chennai represents warm and humid climate and Delhi represents composite climate. The cooling load of the building is different due to the climatic condition and consequently the system performance also differs. Financial viability of the cooling system has been examined through comparison with the energy consumption of conventional cooling system for producing the same cooling effect. Payback period is also calculated.

2. Solar photovoltaic cooling systems

This system is simulated using TRNSYS program v-17. In this cooling system the packaged terminal air conditioner of 10 TR has been chosen operated by the electrical power supplied by the photovoltaic panel. If the power generated by the photovoltaic panel is less than required by the air conditioner then the remaining power will be taken from the grid. If the power generated by the photovoltaic panel is greater than required by the air conditioner then the remaining power will be supplied to the grid. The system is simulated using the mono-crystalline cell.

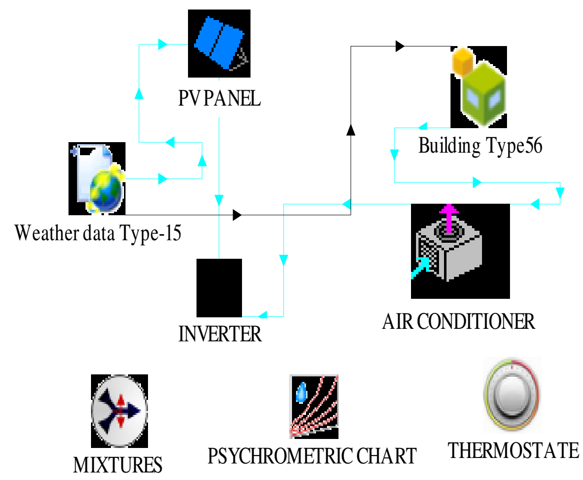


Fig 1 Schematic of Solar Photovoltaic Cooling System

3. Specification of Building coupled with Solar Air Conditioning.

The building being used in this research work is an office building with square envelope of 15m length and 15 m width. The height of the Building is 3.5 meters and total floor area is 225 m^2. Building is divided in the five zones having orientation towards north. The entire building is used for office purpose in the day time only and whole area is conditioned. Windows on all four sides together constitute a WWR of 26%. The detail dimension of Building is shown in the Table 2 and in the Fig 2. Building envelope consists of the parts of building that separate the controlled indoor environment from the uncontrolled outdoor environment. It includes the walls, floor, roof and fenestration (windows, door). Walls, roof and window thickness and materials are selected such that the U-value of construction meets the ECBC requirement.

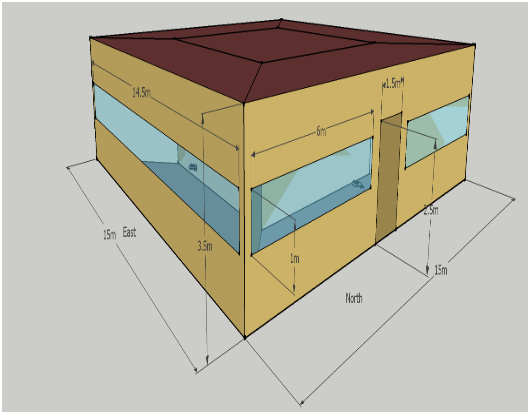


Fig.2:3 D view of Building

Table 2 : Building Zone area and Internal load on Building

S. No	Component	Core Zone	East Zone	West Zone	North Zone	South Zone
1	Zone Vol.(m^3)	212.94	143.64	143.64	143.64	143.64
2	Zone Area(m^2)	60.84	41.04	41.04	41.04	41.04
3	WWR (%)	-	27	27	23	27
2	Infiltration (ACH)	0.2	0.2	0.2	0.2	0.2
3	Ventilation(ACH)	0.75	0.75	0.75	0.75	0.75
4	LPD(W/m2)	10.8	10.8	10.8	10.8	10.8
5	People(Nos.)	8	6	6	6	6
6	Equip. Load(W)	80	80	80	80	80
7	Schedule(Time)	0900-1800	0900-1800	0900-1800	0900-1800	0900-1800

4. Result and Discussion

4.1 Annual cooling load analysis

The cooling load of the five zone buildings having a conditioning area of 225 m^2 are determined using TRNSYS program. From the building cooling model the cooling load can be determined partly as infiltration gain, ventilation gain, sensible gain and latent gain. The total cooling load of a building is the summation of infiltration, ventilation, internal gain and solar gain through walls, windows and roof. The infiltration load is due to cracks, fenestration in the walls and roof, where as ventilation load is due to fresh air supplied to the building. The person sitting inside the building also has a part of sensible and a part of latent heat load. Lighting, equipment, is also responsible for the cooling load. The major part of the load is by solar gain through the walls and windows depending on the U value of the construction materials. In this study the building load is calculated by using TRNSYS simulation program for four cities situated in four different climate conditions.

Fig.3 shows the annual cooling demand and peak cooling load for the different cities selected from different climate zones. It is clear that the peak cooling load is 31.59 kW for Delhi (composite climate) whereas the lowest 20.85 kW is for Bangalore (Moderate climate) while annual cooling demand per square meter of building area is highest 225.64 kWh_{th}/m^2 for Chennai (Warm and humid). This indicates that the peak cooling load is higher in composite climate (Delhi) and hot and dry climate (Ahmedabad) because the variation of temperature is higher there resulting in the peak load but the total cooling load is highest for warm and humid climate (Chennai) where the warm and humid climate increases the latent heat load than others resulting in highest cooling demand. Hot and dry climate (Ahmedabad) is the second highest cooling load city because of longer cooling period.

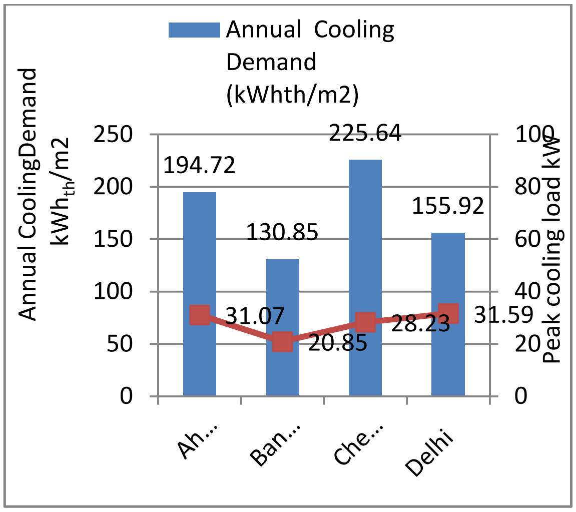


Fig.3: Annual cooling loads and peak cooling load

4.2 Solar Fraction

It is the ratio of the annual cooling produced by the solar to the total annual cooling demand of the building.

Solar Fraction

$$= \frac{\text{Annual cooling produced by solar absor}}{\text{Annual coling demand of build}}$$

Fig 4 shows the variation of annual solar fraction with the photovoltaic area.

It is clear from the fig 4 that as the area of photovoltaic panel is increased the annual solar fraction also increases for all type of panels and climate. The annual power generation directly depends on the area of PV panel so any increase in the PV area increases the power generation and more power directly supplied to the cooling system enhances the solar fraction. The highest solar fraction (0.37-0.57) for mono-cells is observed for the hot and dry climate due to higher power generation, and good matching between the cooling load and power generation in the day time. The lowest solar fraction (0.32-0.49) for mono-cells is observed in the warm and humid climate due to very high cooling load 225 kWh_{th}/m^2 and high annual power consumption of 17912 kWh_{el}.

For moderate and composite climate the annual solar fraction ranges between 0.33-0.51, and 0.35-0.54 respectively. The value of solar fraction for the composite climate is also higher because of the good matching between the power generation and the cooling demand in the summer months.

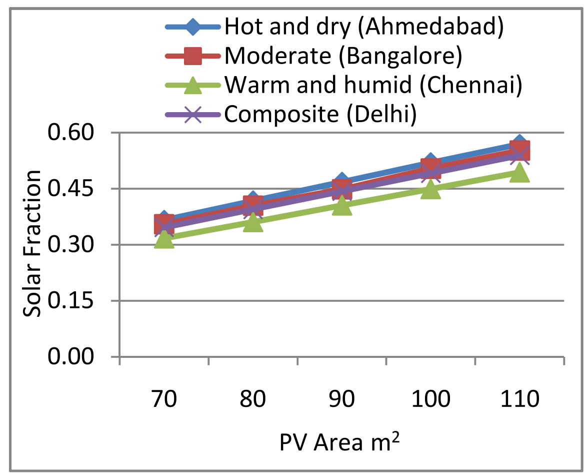


Fig.4 Annual solar fraction

4.3 Primary Energy Savings

Primary energy consumption is calculated from energy consumption of the cooling systems by dividing it to the conversion factor 0.36 [Eicker et al.]. In the solar photovoltaic cooling system the electrical consumption is done by the compressor, condenser fan and blower. The primary energy savings is the difference between the primary energy consumption by the solar photovoltaic cooling system and the primary energy consumption by the compression based cooling system operated by grid power.

Fig 5 shows the primary energy savings for the mono cells. It is clear from the graph that the primary energy savings increase with the PV area for all the climates and type of PV panels. The highest primary energy saving are for the mono cell and lowest for the thin film cells, and for poly cells it is between mono and thin film.

The primary energy savings are highest 36%-56% for the hot and dry climate and lowest for the warm and humid climate, the reason is same as in the annual solar fraction. The cooling demand is very high for the warm and humid climates and power generation is lesser than hot and dry climates resulting in the low primary energy savings in the warm and humid climates, i.e., 31%-49%. The range of primary energy savings in the moderate climate and composite climate are 35-55% and 34-54 % respectively.

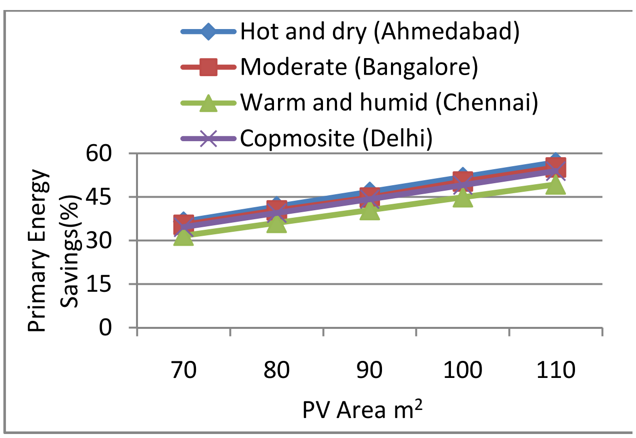
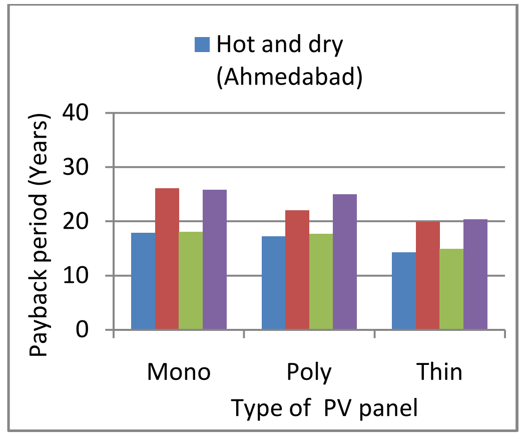


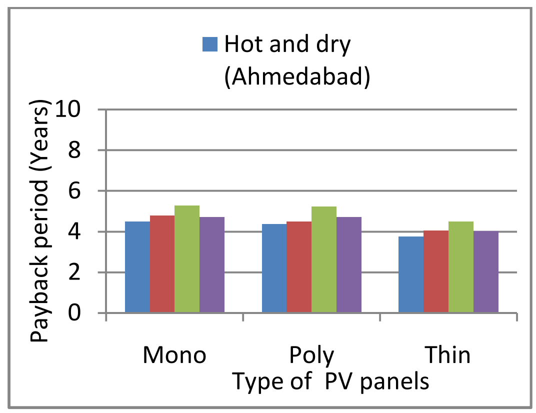
Fig.5 Primary Energy Savings

4.4 Payback Periods:

Fig 6 a and b shows the payback photovoltaic cooling systems based on the present cost structure in India [see appendix]. It is clear from the graph that the payback is higher. In the solar photovoltaic cooling system the lowest payback period is observed for the hot and dry climate that is 14.23 years with the thin film cells. If the PV based systems are optimally used with net metering provisions during the non cooling periods then the payback period is in the range of 4-6 years.



(b)



(c)

Fig.6 Payback periods (a) Solar photovoltaic (b) Solar photovoltaic (with net metering)-Collector/PV area-90m^2

5. Conclusions

In the solar photovoltaic cooling system the S.F. is highest for hot and dry climate (Ahmedabad) and lowest for warm and humid climate (Chennai) due to higher cooling demand in Chennai. Primary Energy Savings increases rapidly with the PV area. Solar photovoltaic cooling system (without net metering) has a high payback period. Lowest payback of 14.23 years is found for hot and dry climate (Ahmedabad) due to good combination of cooling demand and annual electricity generation, for moderate climate (Bangalore) payback is highest 34 years. when PV based systems are optimally used with net metering provisions during the non cooling periods then the payback period is 4-6 years for all climatically zones. In this way this cooling system avoided a large part of CO_2 emission.

6. References

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