RESEARCH ARTICLE OPEN ACCESS

Performance Analysis of Solar Thermal Cooling System for an Office Building in Indian Climates using Flat Plate Collector

[1]B.L.Gupta, [2]Naveen Jha, [3]Dhawal Vyas, [4]Amit Daiya

[1]Department of Mechanical Engineering, Govt. Engineering College Bharatpur 321001 India.
[2]Department of Mathematics , Govt. Engineering College Bharatpur 321001 India.
[3]Department of Computer Science and Engineering, Govt. Engineering College Bharatpur 321001 India.
[4]Department of Civil Engineering, Govt. Engineering College Bharatpur 321001 India.

Abstract:

In this paper performance analysis of solar thermal cooling system for an office building has been analyzed. Analysis has been carried through simulation of a typical office building considered to be located in four different cities, representing four climatic zones of India namely Ahmedabad (Hot and dry), Bangalore (Moderate), Chennai (Warm and humid) and Delhi (Composite). Results indicate that the highest solar fraction has been observed as 0.71, 0.75, 0.77, and 0.78 for hot and dry, moderate, warm and humid and composite climate respectively. The primary energy savings are higher for the moderate climate (Bangalore) and lowest for the warm and humid climate (Chennai).

Keywords — **Solar thermal, Solar Fraction, Primary Energy Savings.**

1. Introduction

The conventional vapour compression refrigeration cycle driven air conditioner using grid electricity, increases the consumption of electricity and fossil energy. Energy sources based on fossil fuels such as coal, oil, gas, nuclear, etc., are cause serious environmental hazards and are scarce in nature, location and volume. To reduce environmental pollution and global warming Balghouthi et al. [2005] suggested the solar power air conditioning in place of conventional vapour compression air conditioning systems. Assilzadeh et al. (2005) carried out the modeling and simulation of absorption solar cooling system with TRNSYS program. Pongtornkulpanich et al. (2008) share the experience with fully operational solar driven 10 ton LiBr/H_2O single effect absorption cooling system in Thailand. They analyzed the data collected during 2006 and show that 72 m^2 evacuated tube solar collector delivered a yearly average solar fraction of 81%, while LPG –fired backup unit supplied the 19% thermal energy. Eicker et al. (2009) develops a full simulation model for absorption cooling systems, combined with a stratified storage tank, dynamic collector model and hourly building loads. They found that depending on control strategy, location and cooling load time series, between 1.7 and 3.6 m^2 vacuum tube collector per kW cooling load are required to cover 80% of the cooling load. Tsoutsos et al. (2010) take for granted that the air conditioning is responsible for a large percentage of the greenhouse and ozone depletion effects. They suggest the solar cooling system for zero emission technologies and to reduce energy consumption and CO_2 emission. Y Hang et al. (2011) carried out economical and environmental assessment of an optimized solar cooling system for a medium sized benchmark office building in Los Angeles (California) having the floor area 4983 m^2. In this building

150 kW capacity absorption chiller was used with varying collector area of 80-490 m^2. The Payback is calculated as 13.8 years when the 40% subsidy is provided on capital investment.

Renato M. Lazzarin (2013) analyzed the solar thermal cooling system with the flat plate, evacuated tube collector and parabolic trough collectors with tracking system. The system are evaluated during sunny days and compared with the PV driven system and found that the PV driven system is now quite comparable. Eicker et al. (2014) performed the primary energy analysis and economic evaluation of solar thermal cooling and solar photovoltaic cooling system, the comparison is made for three different climates corresponding to the Palermo, Madrid and Stuttgart. The cooling systems while in the case of solar thermal system relative primary energy savings reaches 37% in Palermo, 36% in Madrid and 29% in the Stuttgart. Various literature conclude that the primary energy saving and, economic analysis are different for different climates, countries and electric prices.

In the present work parametric study and performance analysis of solar thermal cooling systems has been performed considering the annual solar fraction and relative primary energy savings. In the solar thermal cooling system Flat Plate Collector was used with wide variance of area ranging from 70 m^2-110 m^2 have been considered. 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.

2 Solar Thermal Cooling Systems

This system is simulated using a configuration SCH 601 from the program as shown in the fig 1. This configuration shows the complete heating, cooling and domestic hot water application. In this study only cooling is considered for analysis purpose. The solar thermal cooling system is composed of a solar collector field, solar storage tank, heat exchanger, cold storage tank and vapour absorption chiller. The simulation parameter and their values are shown in table 1.

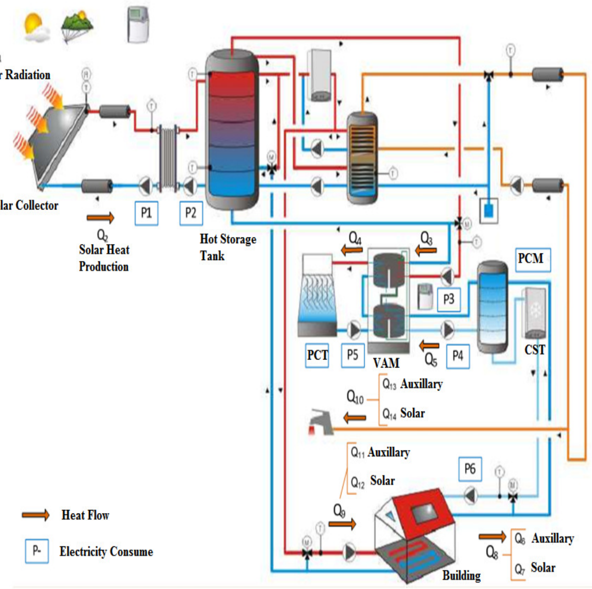

Fig.1: Schematic of solar thermal cooling system [TRANSOL]

Table 1: Parameters considered for simulation of solar thermal cooling system

Component	Parameter	Solar thermal	Source
Solar Collector	Surface Area m^2	70-110 m^2	Henning 2007
Solar Storage	Type	Vertical	Eicker et al. 2014
	Volume	5000 ltr	
Thermal Chiller	Type	Absorption	Mateous et.al 2009
	Nominal Cooling power	35 kW	
	Nominal COP	0.7	
	Pump power	210 W	
Compression Chiller	Nominal cooling power	10.5 kW (Back up)	Eicker et al. 2014
	Nominal COP	3.5	

3 Specification of Building coupled with Solar Thermal 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.

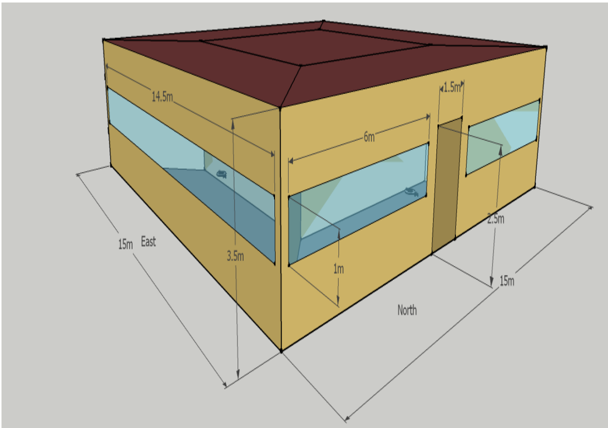

Fig.2: 3 D view of Building

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
3	WWR (%)	-	27	27	23	27
2	Infiltration (ACH)	0.2	0.2	0.2	0.2	0.2
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

4 Annual Cooling Load Analysis

The cooling load of the five zone buildings 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. 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.

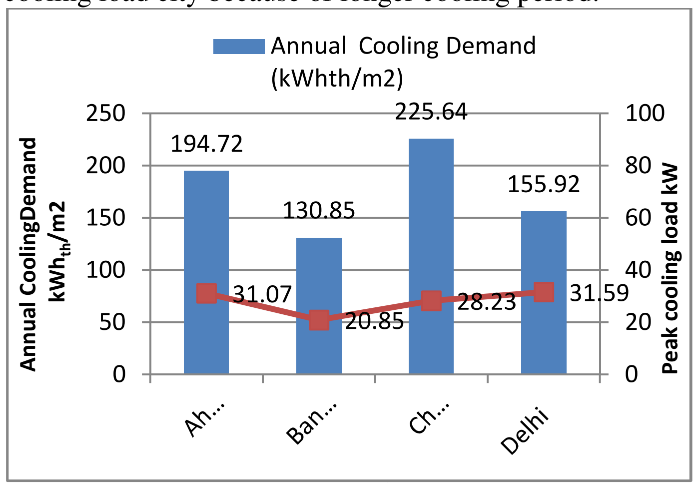

Fig.3: Annual cooling loads and peak cooling load

5 Solar Fraction

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

$$\text{Solar Fraction} = \frac{\text{Annual cooling produced by solar absorption chiller}}{\text{Annual coling demand of building}}$$

Fig 4 shows the variation of solar fraction for different climates and various collector areas. It is clear from the graph 4 that as the collector area increases the solar fraction also increases because more heat is collected by the collector and supplied to the solar thermal cooling system that produce the more amount of solar cooling. The solar fraction is highest for the moderate climate (Bangalore) and lowest for the warm and humid climate (Chennai) because the cooling load of the building is 131kWh$_{th}$/m^2 in the moderate climate is 42% less than the warm and humid climate while the solar radiation is 2094 kWh/m^2 in the moderate climate that is 2% more than the warm and humid climate.

At small collector area of 70 m^2 the annual heat production is low for all the cities and solar thermal cooling system produce the low amount of cooling and in this condition the solar fraction is 66% for moderate climate (Bangalore) due to low cooling load and it is 59% for hot and dry climate (Ahmedabad), for warm and humid climate (Chennai) 51%, and for composite climate (Delhi) it is 63%. It is very low for the warm and humid climate (Chennai) because of the very high cooling load 225 kWh$_{th}$/m^2 and low incident radiation compared to other climates. As the flat plate collector area increase from 70 m^2 to 110 m^2 the solar fraction for all cities increases because more heat is collected by the collector but its effect will be much more if this heat is effectively utilized to produce the cooling effect. In the warm and humid climate (Chennai) the building cooling load is very high and the heat is effectively utilized so change in solar fraction is higher with the increase in collector area than other cities. If the collector area is increased from 70 m^2 to 110 m^2 the solar fraction increases from 51 % to 71 % in warm and humid climate (Chennai), 59% to 75 % in hot and dry conditions (Ahmedabad), 66% to 77% in moderate climate (Bangalore) and 63% to 78 % in composite climate(Delhi)

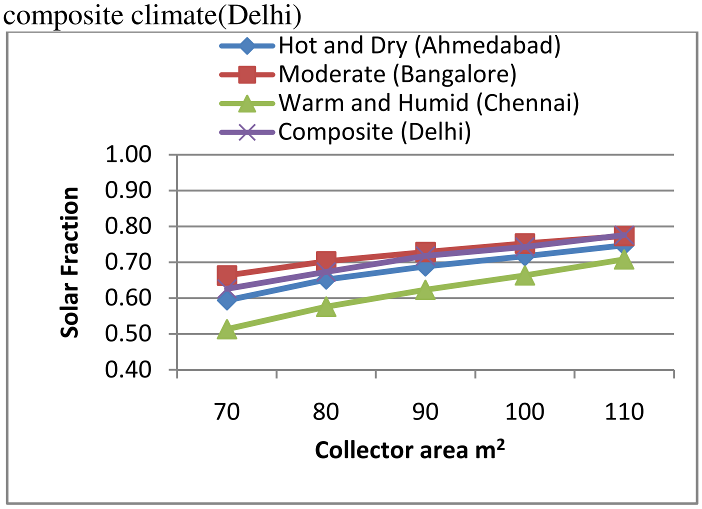

Fig. 4 Variation of Solar Fraction with collector area

6. 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 thermal cooling system the electrical energy is consumed by pumps, controls and electrical chiller used as a backup. 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 thermal cooling system and the primary energy consumption by the compression based cooling system operated by grid power.

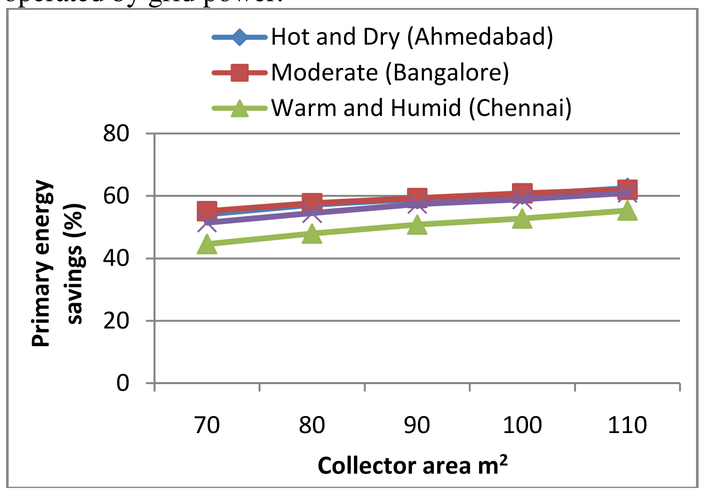

Fig. 5 Variation of Primary Energy Savings with collector area

Fig 5. shows the variation in primary energy savings with different collector areas. It is observed from the graph 5 that the primary energy savings are increased with the increase in collector area (FPC), because more heat is collected by the solar thermal collector for the same cooling demand. The primary energy savings are higher for the moderate climate (Bangalore) 55-62 % and lowest for the warm and humid climate (Chennai) 44-55%. It is between 54- 62 % for the hot and dry climate (Ahmedabad) and 51 - 61 % for the composite climate (Delhi). The primary energy savings are highest for moderate climate due to very low cooling demand of 131 kwh$_{th}$/m^2 and the primary energy savings are lowest for the warm and humid climate (Chennai) because of the very high cooling demand of 225 kwh$_{th}$/m^2.

7. Conclusions

The solar thermal cooling system is a feasible solution to reduce the environmental pollution and global warming. The highest solar fraction has been observed as as 0.71, 0.75, 0.77, and 0.78 for hot and dry, moderate, warm and humid and composite climate respectively. The primary energy savings are higher for the moderate climate (Bangalore) 55-62 % and lowest for the warm and humid climate (Chennai) 44-55%. It is between 54- 62 % for the hot and dry climate (Ahmedabad) and 51 - 61 % for the composite climate (Delhi).

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