

Performance Evaluation of Evaporative Air-Conditioning System for Truck Cabins in Indian Environmental Conditions

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ABSTRACT: Recent increase in the demand of air-conditioning for commercial and transport vehicles has forced the designers to work upon the fuel efficient and environment friendly air conditioning system, as the conventional air-conditioning system consumes significant amount of fuel energy thus they adding to the environment pollution. Research work done on alternative air-conditioning system like evaporative air-conditioning system in India is very less as compared to European countries and elsewhere. As evaporative air-conditioning system is based on water as cooling media and air as a working fluid, hence evaporative air-conditioning system has great potential to provide thermal comfort with reduced pollution & fuel consumption. The present work deals with the performance evaluation of an air conditioning system based on evaporative cooling developed for Indian environmental conditions. The results indicate that evaporative air-conditioning in the commercial vehicle truck is useful in the most part of the India and can be used as an alternative of conventional vapour compression air-conditioning.

KEYWORDS: Air-conditioning System, Vapour Compression Air-conditioning.

I. INTRODUCTION

The past few decades had witnessed an increase in industrial and human activities which has resulted in increase of commercial vehicle densities all over the world. Recent studies suggested that the use of air-conditioning systems in automotive vehicles is growing day by day, hence there is need to explore the need of alternative air-conditioning systems in place of conventional VCR air conditioning systems, which consumes a significant proportion of power derived from automobile engine [11]. India is the seventh largest country by geographical area, the second most populated country in the world. Hence day by day need of air-conditioning is increasing in Indian automotive vehicles including commercial vehicles. Hence need of alternative fuel efficient air-conditioning system for Indian environmental conditions is very much essential [4].

Bhatti S. Mohinder has provided information about the historical development of automotive air conditioning from 1930s to 1990s. The study described, prior to 1930 Adjustable windshields were provided for increased air flow and comfort in the automobiles. In 1930 Kelvinator outfitted a customized Cadillac 0.37 kW VARS Kelvinator refrigeration unit powered by a 1.1 kW gasoline engine [1]. Shah R. K has done comprehensive review of automotive air-conditioning systems. In his study he briefly summarized the current auto air conditioning system and done the historical review of the refrigerant from R12 to R 134a [2]. Rugh J. et al had done research on impact of vehicle air-conditioning on fuel economy, and tailpipe emissions. In the research author highlighted that current air conditioning systems can reduce the fuel economy of higher commercial vehicles USA by about 50% [3]. Chaney L. et al had done his research on fuel savings and emission reductions from next generation mobile air conditioning technology in India [4]. Guerra J. had shown that evaporative air conditioning system can be an alternative air-conditioning system for

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(An ISO 3297: 2007 Certified Organization)

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passenger car which is environmentally safe and efficient [5]. Camargo J R et al research work shown that a system that can be used in humid climates couples desiccant dehumidification equipment to evaporative coolers [6]. Kushwaha Shiv Kumar et al had made an evaporative air conditioner prototype and fitted in conventional bus. In his research work performance of evaporative air conditioner had been evaluated in summer condition [7]. Bom Gelit Jan et al had presented the benefits of evaporative air conditioning system, opportunities and limitation of evaporative air conditioning systems [8].

In the present work global issue related to the depleting energy resources like fossil fuels used in the present vehicles and related environmental concerns had been addressed by exploring the use of evaporative based air conditioning system in commercial vehicles. The performance evaluation of evaporative air conditioning system implemented in commercial trucks was done and results were reported for different environmental conditions.

II. EVAPORATIVE AIR CONDITIONING

Evaporative air conditioning effect produced when water and dry air comes in contact. In evaporative air conditioning system temperature of the working air reduced when it comes in contact with water and some amount of water evaporated, latent heat required for the evaporation of water taken from the air which were in contact with water thus the temperature of air reduced and this chilled air then used for the air conditioning.

Schematic diagram of an evaporative air conditioning system for commercial vehicle truck is shown in Fig. 1. Water feed pump (2) is placed in the bottom side of the water tank. Water is sent upwards by water feed pump (2) through water filter (5) in the roof unit through feeding tube (A). Straw water absorber (10) placed inside the roof unit. Water coming from the reservoir enters into the straw water absorber (10) and infiltrates, some excess water drops into the drain tray (12) and return back to the water tank through return tube (B). Blower motor (7) pulls outside air (C) through straw water absorber (10) which was infiltrated with water. When outside air comes into the contact with the infiltrated water some amount of water evaporated and temperature of outside air get reduced due to evaporative air cooling. Conditioning air from straw filter (10) pushed into the cabin by blower motor (7) through grills (9) placed at the lower side of evaporative unit and air condition of cabin occurred through this evaporative air conditioning cycle.

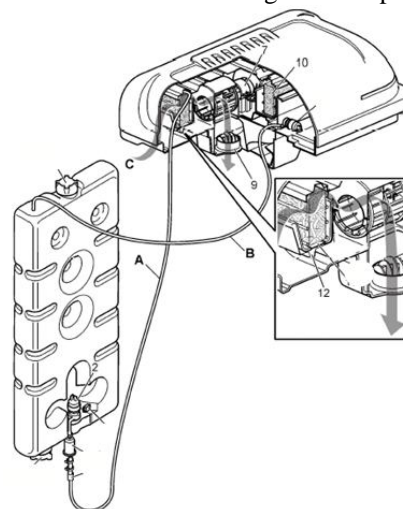


Fig. 1 Schematic evaporative air conditioning system [12]

Advantages of evaporative cooling over VCR air-conditioning are, (a) limited power consumption to the fan and water pump as there is no compressor that consumes most of the power in closed-cycle refrigeration, (b) cooling media used for evaporative air conditioning is water which is nontoxic and (c) air flow used in air conditioning is fresh and healthy.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

III. EXPERIMENTAL SETUP

The experiments were carried out on heavy commercial vehicle trucks with sleeper cabin typically used in Indian conditions. For evaporative air conditioning system prototype fitment performance testing of evaporative air conditioning system existing 6x4 tipper heavy commercial vehicle trucks with sleeper cabin with internal volume 5m^3 and external dimension (cabin) $1.6\text{m} \times 2.1\text{m} \times 1.5\text{m}$ with passenger capacity of 3 persons used. Three conventional trucks had been selected and EAC prototypes had been fitted for performance evaluation of evaporative air conditioning system in different Indian environmental conditions.

Evaporative air condition system prototype had 12V blower unit (200Watt power and $450\text{m}^3/\text{hr}$), water tank (18litres capacity), water feed pump (79.2m/s water feed rate), water feed tube and water return tube had been used for prototype fitment on heavy commercial vehicle truck and performance testing as shown in Fig.2. For performance testing of evaporative air conditioning system in commercial vehicle truck one hot wire anemometer having least count of 0.1m/s was used for velocity measurement, thermocouples having resolution of 1°C was used for temperature measurement, one digital humidity meter used for humidity measurement and one Hioki data logger was used for temperature data collection during the performance testing.

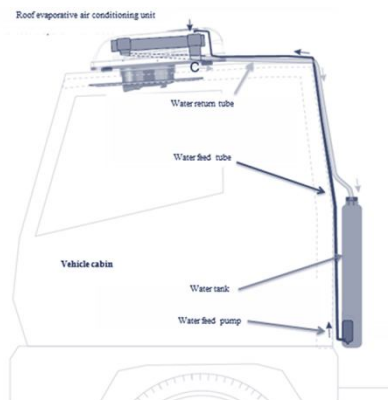


Fig.2Evaporative air conditioner system schematic [12]



Fig.3Prototype evaporative air conditioner system with roof top unit fitted in conventional trucks

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

IV. PERFORMANCE TESTING

Performance evaluation of evaporative air conditioning system has been done on the selected commercial heavy duty trucks in afternoon of summer season.

*Roof Cooler Testing :
Average Summer Conditions : Indian Weather*

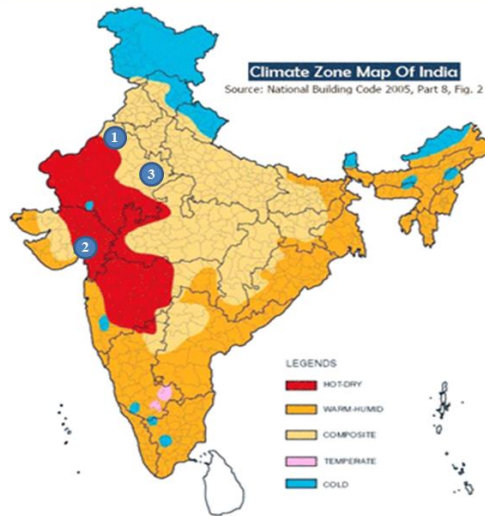


Fig. 4 India summer condition zonal temperature map [4]

Following zones were selected for the testing, (1) hot & dry (covering 20-25% area, RH below 30%)-Kota (Rajasthan), (2) hot & humid (covering 25-30% area, RH above 45%)-Mumbai (Maharashtra), (3) composite (covering 30-35% area, RH 30-45 30%)-Pithampur (Madhya Pradesh).

As per the ARAI (Automotive Regulatory Authority of India) standard the trucks were kept in afternoon in summer condition for two hours with all windows closed initially. The inside conditions were recorded and thereafter the evaporative air conditioning system was switched on and the performance was evaluated under the following test conditions.

Table 1 Vehicle condition performance testing

Testing Conditions			
Condition	Window Condition	Cooling Unit (On\Off)	Test Duration
Condition 1(C1)	All windows closed	Off	20 minutes
Condition 2(C2)	All Window Closed	On	20 minutes
Condition 3(C3)	50 mm window Open	On	20 minutes
Condition 4(C4)	50% window Open	On	20 minutes
Condition 5(C5)	All Window Open	On	20 minutes

Detailed Performance test results of evaporative air conditioning system in hot and dry, humid & moderate ambient are shown in Table no. 3(a), (b) & (c). From the below table it seems that (a) In zone1: hot & dry zone, Kota (Rajasthan) average cabin temperature drop achieved was 5.5°C (test condition - LH & RH door glass opened by 50mm). (b) In zone 2: hot & humid Zone, Mumbai (Maharashtra) average cabin temperature drop achieved was 10°C (test condition - LH & RH door glass half and fully opened). (c) In zone 3: composite zone, Pithampur (Madhya Pradesh) average cabin temperature drop achieved was 7°C (test condition - LH & RH door glass half and fully opened).

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Table 2 Evaporative air conditioning system performance test results

(a) High ambient region

Test Duration	Cabin Condition	Vehicle Speed (Km/Hrs)	Roof Cooler On\Off	Ambient Temperature (in °C)	Driver Nose Level Temperature (in °C)	Temperature Drop Driver Nose From Cabin Soaking Temperature	Co-Driver (Temp)	Temperature Drop Co-driver Nose From Cabin Soaking Temperature	Co-driver Nose Level Temperature (in °C)	Humidity Ambient (in RH%)	Humidity Inside Cabin (in RH%)
Initial Reading	C1 : Completely Close	0	Off	41	44	0	45	0	45	32%	33%
After 20 Minute	C2 : Completely Close	40	ON	45	41	3	42	3	44	32%	43%
After 40 Minute	C3 : Lh & Rh door glass opened by 50mm	40	ON	42	39	5	40	5	43	34%	37%
After 60 Minute	C4 : Lh & Rh door glass 50% opened	40	ON	43	40	4	40	5	41	32%	35%
After 80 Minute	C5 : Lh & Rh door glass opened Completely	40	ON	44	40	4	42	3	42	32%	35%

(b) High humid coastal region

Test Duration	Cabin Condition	Vehicle Speed (Km/Hrs)	Roof Cooler On\Off	Ambient Temperature (in °C)	Driver Nose Level Temperature (in °C)	Temperature Drop Driver Nose From Cabin Soaking Temperature	Co-Driver (Temp)	Temperature Drop Co-driver Nose From Cabin Soaking Temperature	Co-driver Nose Level Temperature (in °C)	Humidity Ambient (in RH%)	Humidity Inside Cabin (in RH%)
Initial Reading	C1 : Completely Close	0	Off	36	43	0	43	0	43	45%	39%
After 20 Minute	C2 : Completely Close	40	ON	36	35	8	36	7	35.5	46%	58%
After 40 Minute	C3 : Lh & Rh door glass opened by 50mm	40	ON	36	35	8	35	8	35	45%	53%
After 60 Minute	C4 : Lh & Rh door glass 50% opened	40	ON	36	33	10	34	9	33.5	46%	48%
After 80 Minute	C5 : Lh & Rh door glass opened Completely	40	ON	35	33	10	33	10	33	50%	53%

(c) Low ambient region

Test Duration	Cabin Condition	Vehicle Speed (Km/Hrs)	Roof Cooler On\Off	Ambient Temperature (in °C)	Driver Nose Level Temperature (in °C)	Temperature Drop Driver Nose From Cabin Soaking Temperature	Co-Driver (Temp)	Temperature Drop Co-driver Nose From Cabin Soaking Temperature	Co-driver Nose Level Temperature (in °C)	Humidity Ambient (in RH%)	Humidity Inside Cabin (in RH%)
Initial	C1 : Completely Close	0	Off	42	44	0	45	0	44.5	28%	35%
After 20 Minute	C2 : Completely Close	40	ON	42	38	6	39	6	38.5	28%	39%
After 40 Minute	C3 : Lh & Rh door glass opened by 50mm	40	ON	42	37	7	38	7	37.5	37%	38%
After 60 Minute	C4 : Lh & Rh door glass 50% opened	40	ON	41	37	7	37	8	37	34%	37%
After 80 Minute	C5 : Lh & Rh door glass opened Completely	40	ON	41	37	7	37	8	37	31%	33%

The results of performance testing indicate that the drop in temperature achieved may not be very high but it is still satisfactory for all the selected zones considering the evaporative air cooling. The performance was reported to be more satisfactory in hot and dry environmental conditions as compared to the humid environmental conditions. In high ambient zones, water tank of 18litres were able to supply water for 4.5 hours as needed to be filled again. Evaporative air conditioner is performance seems to be better in partial & 50mm window open condition and 50% window open condition, but performance of evaporative air conditioner is not very much effective in window closed condition subjectively.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Although the cooling capacity of the evaporative air conditioning system is less than the conventional VCR based air conditioning system but due to the gain in fuel economy associated with the evaporative air conditioning system (due to less power consumption) it may be preferred over conventional air conditioning system for most Indian environmental conditions (most useful in the hot and moderate environmental conditions). Evaporative air conditioning system was found to be less effective in the coastal zones as per the subjective feedback of occupants during the testing. The results indicated better performance if the windows of the cabin remain partially open as the fully closed windows may cause discomfort due to increased humidity.

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