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Calculation & Performance of an Evaporative Cooling System (EAC) on Conventional Bus

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***Abstract* - India is counted as hot countries amongst all over the world, because sun rays falling directly and horizontally most part of the it , living surroundings for the duration of summer go extreme with temperature rising up to 46˚ C. The environment further goes worse when the humidity levels are very low. The situations go harsh while travelling. This research paper has been performed to provide suitable way out to this problem keeping this background in preview. The research has been targeted to provide air conditioning comfort in rural travelling conditions and to initiate the idea, a conventional bus conditions are chosen for experimentation. A cheap means of air-conditioning has been designed which can be used for local and mass transport means. The idea is to provide air-conditioning comfort to common man with least investment and minimum operating cost.**

Keywords – Air - Conditioning, Bus Air Conditioning, Evaporative Cooling, Dry Blub Temperature, Wet Blub Temperature, Relative Humidity, Ambient Temperature Difference, Solar Temperature Difference, Heat Load, Sensible Heat, Latent heat.

I. INTRODUCTION

India is the 7th major country by geographical area, the 2nd most populated country in the World with over 1.25 billion citizens. 70% of this population lives in rural areas. For the period of summer due to lack of proper transportation facilities means common man of residents journey in non air conditioned buses and high temperature make such journeys terrible. With the support of evaporative cooling this research paper attempts to reduce the heat load of a conventional bus. The study is based on weather data of Bhopal, India in summer month of May. An evaporative cooling system trial prototype was designed which was installed on the 52-seater bus. Experiments were conducted during hot summer environment and results were analyzed. The analysis concludes that applying an evaporative cooling system on conventional bus for thermal comfort results in lesser maintenance cost and operating cost. Additionally evaporative cooling is effective, environmentally friendly economical and healthy [1].

II. BACKGROUND

Evaporative cooling is a substantial phenomenon in which evaporation of a liquid, typically into atmospheric air, cools an object or a liquid in contact with it. Latent heat, the quantity of heat that is desired to evaporate the liquid, is drawn from the air. When taking into consideration water evaporating into air, the wet-bulb temperature (WBT), as compared to the air's dry-bulb temperature (DBT) is a measure of the potential for evaporative cooling. The larger the difference between the two temperatures, the larger the evaporative cooling effect. When the temperatures are similar, no remaining evaporation of water in air occurs; as a consequence there is no cooling outcome. Evaporative cooling involves heat and mass transfer, which occurs while water and the unsaturated air-water mixture of the incoming air are in contact. This transfer is a function of the differences in temperatures and vapor pressures between the air and water. Heat and mass transfer is both functioning in the evaporative cooler because heat transfer from the air to the water evaporates water. The water evaporating into the air constitutes mass transfer. Heat inflow can be described as either latent or sensible heat. Whichever term is used depends on the effect. If the effect is only to raise or low temperature, it is sensible heat. Latent heat, produces a change of state, e.g. condensing, vaporizing, freezing or melting. In evaporative cooling, sensible heat from the air is transferred to the water, appropriate latent heat as the water evaporates [2].

International Research Journal of Engineering & Applied Sciences
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The water vapor becomes part of the air and carries the latent heat with it. The air dry-bulb temperature is decreased because it gives up sensible heat. The air wet bulb temperature is not affected by the absorption of latent heat in the water vapor because the water vapor enters the air at the air wet-bulb temperature. Theoretically, the incoming air and the water in the evaporative cooler may be considered an isolated system. Because no heat is added to or removed from the system, the course of action exchanging the sensible heat of the air for latent heat of evaporation from the water is adiabatic. Evaporative cooling system performance is based on the concept of an adiabatic process.

EVAPORATIVE COOLER

Evaporative coolers are used with gas turbines to increase the density of the combustion air, thereby increasing power output. The air density increase is accomplished by evaporating water into the inlet air, which decreases its temperature and in the same way increases its density. The water vapor passes through the turbine, causing a negligible increase in fuel consumption. Water used with evaporative coolers often contains dissolved solids such as sodium and potassium, which, in combination with sulfur in the fuel, are principal ingredients in hot gas path corrosion.

For this reason, water quality and the prevention of water carry-over are important considerations in the use of evaporative coolers. The prevention of water carry-over is accomplished by correct design of the evaporative cooler, and proper installation and operation. Water quality requirements depend on the amount of water carry-over expected (or allowed) and can vary from the use of deionized water to water with significant concentrations (as much as several hundred ppm by weight, in water) of sodium and potassium.

III. EXPERIMENTAL SETUP

The experiments were carried out on common passenger bus typically used in Indian conditions. The conventional home coolers with AC current were used for experimental purpose.

Fig3.1- An image of experimental setup of bus (52 seater)

The bus selected for experiment was in stationary condition facing towards West direction. It was exposed from all side without any effect of tree or building shadows.

BUS SPECIFICATIONS

Type: Conventional School Bus
Seat: 52 (Seated)
Length: 30’ (Ft)
Width: 7.5’ (Ft)
Window size: 4’ × 2.5’ ^{2} ft
No of window (north side): 8
No of window (south side): 8

Fig 3.2- An image of desert cooler used for experimental setup

Two desert coolers were fixed on the bus. One was on north side window and other was on south side. The flow arrangements of both coolers were inside the bus cabin and opposite of each other. The cooler water tank was filled initially to up to brim.

COOLER SPECIFICATIONS

Voltage: 230 V ; AC : 50 Hz
Wattage: 180 W
Water tank capacity: 65 liters
Dimensions: 450 × 430 × 670 mm
Air Delivery:440M^3/Hr.(measured by anemometer)

The velocity anemometer was used for velocity measurement of coolers and the grill area was multiplied to obtain flow rates taking into consideration the area of vanes in the grill. It can be noticed that the flow rate is very low as compared to conventional coolers available in the current market. This is because the coolers used for experimentation were old modeled. In actual running conditions DC coolers have to be used which can be operated with Bus dynamo current or battery.

International Research Journal of Engineering & Applied Sciences
www.irjeas.com, ISSN(o): 2322-0821, Volume 3, Issue 1, January 2015 – March 2015, Page 07-13

MEASURING DEVICES

Thermometer: Two thermometers were used, one for DBT measurement and other for WBT measurement with usual wet cotton lump. The least count of each was 1°C.

Fig3.3- DBT and WBT Thermometers.

Anemometer: A digital anemometer was used for air velocity measurement having least count of 0.1m/s.

Fig3.4- Anemometer used in experiment

IV. EXPERIMENTAL APPROACH

Experiment was carried on 52 seated conventional bus on during may 2012 that is peak time of summer. As per the ARAI (Automotive Regulatory Authority of India) standard for evaluating performance of automotive air conditioning system performance, the bus was soaked in summer noon sun for one hour. The occupancy was nil and all windows were closed. After soaking the initial inside conditions were recorded. The coolers were now started and the effect was analyzed by recording the temperatures both DBT and WBT inside the bus after every five minutes. The temperatures were recorded at three positions i.e. at driver seat, in the middle and the third at end seat. The thermometers were installed at these positions in the longitudinal center line. The three readings were averaged.

GRAPHICAL ANALYSIS

At the end the decrease in water level was noted for calculating the total water consumption during the duration of the experimental run. The DBT and WBT readings inside the bus are presented in graphical form as shown below:

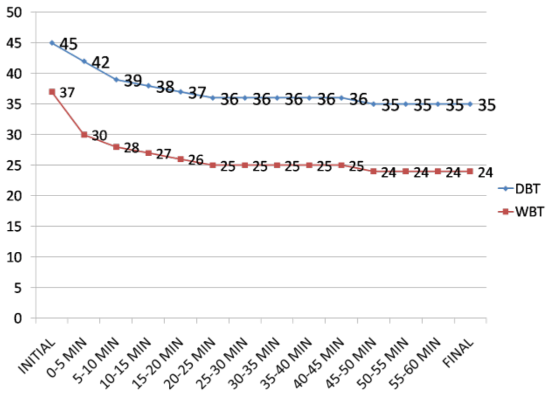

Fig 4.1- Graph between DBT and WBT Vs Time

V. CALCULATIONS

Summary of Preliminary Water Consumption Test Results						
Cooler	Initial Readings (In cm.)			Final Readings (In cm.)		
C	W_1	D_1	H_1	W_2	D_2	H_2
C1	63.5	50.8	19.81	63.5	50.8	16.51
	W_3	D_3	H_3	W_4	D_4	H_4
C2	71.12	55.88	16.51	71.12	55.88	13.20

Table 5.1- Water consumption of cooler

WATER CONSUMPTION RATE

Calculation of Water Consumption for Cooler C1

Initial reading from Table 5.1
W_1 = 63.5cm, D_1 = 50.8cm, H1 = 19.81cm

$$V_1 = W_1 \times D_1 \times H_1$$
$$= 63.5 \times 50.8 \times 19.81$$
$$= 63903.098 cm^3$$
$$= 63903.098 \times .001$$
$$= 63.9 liter^3$$

Final reading from Table 5.1
W_2 = 63.5cm, D_2= 50.8cm, H_2 = 16.51 cm

International Research Journal of Engineering & Applied Sciences
www.irjeas.com, ISSN(o): 2322-0821, Volume 3, Issue 1, January 2015 – March 2015, Page 07-13

$V_2 = W_2 \times D_2 \times H_2$

$= 63.5 \times 50.8 \times 16.51$

$= 53257.958 cm^3$

$= 53257.958 \times .001$

$= 53.25 liter^3$

Water Consumption rate of Cooler (C1)
= V1 - V2
= 63.9 – 53.3
= 10.6 Lit./hr.

Calculation of Water Consumption for Cooler C2

Initial readings from Table 5.1
W_3 = 71.1 cm, D_3 = 55.9cm, H_3 =16.51cm

$V_3 = W_3 \times D_3 \times H_3$

$= 71.12 \times 55.88 \times 16.51$

$= 65613.8043 cm^3$

$= 65613.8043 \times .001$

$= 65.61 liter^3$

Final readings from Table 5.1
W_4 = 71.1 cm, D_4 = 55.88 cm, H_4 = 13.2 cm

$V_4 = W_4 \times D_4 \times H_4$

$= 71.12 \times 55.88 \times 13.20$

$= 52459.2499 cm^3$

$= 52459.2499 \times .001$

$= 52.45 liter^3$

Water Consumption rate of Cooler (C2)
= V1 - V2
= 65.6 – 52.5
= 13.4 Lit. /hr.

HEAT LOAD CALCULATION FOR BUS [4,5]

Coach has to work under widely varying conditions of ambient temperature, latitude, passenger load etc. In deciding the capacity of plant certain assumptions regarding number of adverse condition of the working are to be made and based on these assumptions the plant capacity required is worked out.

Data and constants are used and the assumptions made are,

Coefficient of heat transfer (k) in k-Cal/Hr/m2/°C For,

Wall and end partitions = 0.615
Roof = 0.65
Floor = 0.72
Window (Conduction) = 1.94
'U' for window = 5.34

The interior temperature in relation to the exterior temperature and relative humidity to be maintain when operated with full complement of 52 passengers, lighting and fan load etc.

	DBT (°C)	WBT (°C)	RH %	Moisture Gains.*
Outside Conditioned	45	25	20	110
Inside Conditioned	25	-	55	60

Table 5.2 - Final reading of DBT & WBT and Temperature difference with Moisture Gains.

TD = 20 and GD = 50

T.D. for end portions is always considered to be 3°C less than T.D. for other parts of the coach, since non-air conditioned space adjacent to the air conditioned compartments is considered to have a temperature of 3°C less than the ambient temperature.

Solar Temp. Difference (TDS)
Side wall = 9° C
Roof = 10.55°C
Window = 95.55°C
Requirement of clean and fresh air for non-smoking compartments
= 0.35m^3 /passenger/ minute.
Quantity of ventilating air for 52 passengers (Q)
= 0.35 × 52
= 18.2m^3 / minute
= 18.2 × 35.3
= 642.46 Ft^3 /minute
(CFM)

The following are the wattages considered for various-electrical appliances. 10 Fluorescent tube light - 24 W. Even though the wattage of the tube is 20 W, the choke also consumes power. Hence, 1.2 times the wattage i.e. 1.2 x 20 = 24W has been considered for the purpose of heat load calculations.

Heat transfer from fluorescent lights and = 3.4 BTU/Watt/Hr. incandescent lamps
Sensible heat per passenger = 205 BTU/Hr. (51.6 K.Cal/Hr)
Latent heat per passenger = 195 BTU/Hr (49.12K.Cal/Hr)
1 Ton of refrigeration = 12000 BTU/Hr. (3024 K.Cal/Hr)
1 k-calorie = 3.97 BTU/Hr.

DIMENSIONS OF COACH

Length of Bus (A) = 10. M

Width of roof (B) = 2.3 M
Width of floor (C) = 2.3 M
Height of Bus (D) = 2.2 M
Area of both side wall= $2\times$ (A $\times$ D)

$= 2\times2.2\times10 = 44.0\ M^2$

Area of roof (A $\times$ B) = 23.0 M^2

Area of floor (A $\times$ C) = 23.0 M^2

Area of back side wall = 3.16 M^2

Area of front side wall = 3.16 M^2

Total wall area = 44+3.16+3.16 = 50.32 M^2
Height of window = 0.61 M
Width of window = 1.22 M

Area of window 0.61 $\times$ 1.22 = 0.74 M^2
No. of windows per side wall = 08
Total area of windows per sidewall = 0.74 $\times$ 08
= 5.95 M^2

Back side glass Area = 0.91 $\times$ 2.13 = 1.94 M^2

Front side glass Area = 0.91 $\times$ 2.13 = 1.94 M^2
Total Glass Area = (5.95$\times$ 2) +1.94 + 1.94
= 15.78 M^2
Total area of wall excluding glass = 50.32 – 15.78
= 34.54M^2.

Connected Electrical Loads Inside Compartment Fluorescent lights = 10 Nos.

Heat gain due to conduction = A $\times$ K $\times$ TD $\times$ 3.97 BTU/Hr.
Side wall: 34.54 $\times$ 0.615 $\times$ 20 $\times$ 3.97
= 1686.62 BTU/Hr.
Roof: 23 $\times$ 0.65 $\times$ 20 $\times$ 3.97 = 1187.03 BTU/Hr.
Floor: 23 $\times$ 0.72 $\times$ 20 $\times$ 3.97 = 1314.86 BTU/Hr.
Window :15.78 $\times$ 1.94 $\times$ 20 $\times$ 3.97 = 2430.69 BTU/Hr.
Total : 1686.62 +1186.03 +1314.86 +24302.69
= 6619.2 BTU/Hr. ……………………………......(i)

Solar Heat Gain= *A $\times$ K $\times$ TDS $\times$ 3.97*
Side wall :(22-5.95) $\times$ 0.615 $\times$ 9 $\times$ 3.97
= 352.68 BTU/Hr.
Roof : 23 $\times$ 065 $\times$ 10.55 $\times$ 3.97 = 626.16 BTU/Hr
Window : 5.95 $\times$ 5.34 $\times$95.55 $\times$ 3.97
= 12052.56 BTU/Hr.
Total : 352.68 + 626.16 + 12052.56 = 13031.4 BTU/HR ……………………………………..…(ii)

Heat gain due to passengers (BTU/Hr.)

S.H. = 205 $\times$ No. of passengers.
L.H. = 195 $\times$ No. of passengers.

S.H + L.H = 400 $\times$ No. of passengers.
=400 $\times$ 52 = 20800BTU/Hr.………….…….....(iii)

Heat gain due to ventilation (BTU/Hr.)

Q = Ventilation Air Flow = 52 person $\times$ 5 cfm/person
= 260 cfm
S.H. = 1.08 $\times$ Q $\times$TD$\times$1.8
= 1.08 $\times$ 260 $\times$ 20 $\times$ 1.8
= 10108.8 BTU/Hr.
L.H. = 0.68 $\times$ Q $\times$ GD
= 0.68 x 260 x 50 = 8840 BTU/Hr.
Total = 24978.84 +21843.46
= 18948.8 BTU/H. ……………………….........(iv)

Heat gain due to elect, appliances

= Wattage $\times$ 3.4 BTU/Hr. or, H.P. $\times$ 3600 BTU/Hr.
Fluorescent Light 20W = (20 $\times$ 1.2) W.
= 1.2 $\times$ 20 $\times$ 3.40 $\times$ 10 = 816 BTU/Hr.
Total= 816 BTU/Hr. ..…………..……………….(v)

Total = i + ii + iii + iv + v
= 6619.2 + 13031.4 + 20800 + 18948.8 + 816 + 573.19
Gross Total Heat gain = 60215.4 BTU/Hr.

Refrigeration Capacity (TR)= $\frac{60215.4}{12000}$
= 5.02 TR

Vehicle Energy Consumption Information: [6]

The typical fuel consumption of a engine of a bus is on the order of 0.315 L/kWh. Another element in fuel consumption is weight. A 2% increase in vehicle weight results in an increase of 1% in fuel consumption. This translates into a 0.15 Lit increase in fuel usage for every 300 kg increase in weight.

Energy consumption by evaporative cooler

Required air flow to cool the bus = 2944 cfm
Required power to run the fan motor = 500 W
Required power to run the pump = 15 W
Total weight of equipment setup including water = 300 Kg.

Fuel consumption by evaporative cooler
= (500+15) x 0.315/1000 = 0.162 lit/hr.
Fuel consumption due to weight of equipment
= 300 x 0.15/300 = 0.15 lit/hr.
Total fuel consumption = 0.162 + 0.15 = 0.321 lit/hr.

International Research Journal of Engineering & Applied Sciences
www.irjeas.com, ISSN(o): 2322-0821, Volume 3, Issue 1, January 2015 – March 2015, Page 07-13

If evaporative cooler runs 12 hr in a day
Then fuel consumption by evaporative cooler per day = 12 x 0.321 = 3.85 lit.
And fuel consumption by evaporative cooler per annum = 365 x 3.85 = 1405.25 lit.

Energy consumption by bus AC

Required ton to cool the bus = 5.02 TR
Total power required to run the AC= 6 KW
Total weight of equipment = 250 Kg.
Fuel consumption by bus AC = 6 x 0.315= 1.89 lit/hr.
Fuel consumption due to weight of equipment = 250 x 0.15/300 = 0.125 lit/hr.
Total fuel consumption = 1.89 + 0.125 = 2.015 lit/hr.

If AC runs 12 hr daily
Then fuel consumption by bus AC per day = 12 x 2.015 = 24.18 lit.
And fuel consumption by bus AC per annum = 365 x 24.18 = 8825.7 lit.
Total fuel saving per annum by evaporative cooling = 8825.7 – 1405.25
= 7420.45 lit.

Sr. No.	Basic characteristics	Evaporative Cooling	Bus Air Conditioning
1	Coolant	Water	CFCs/HFCs
2	Production residential coolers	Small and large scale	Small and large scale
3	Sensitivity to humidity for comfort cooling applications	Applicable in dry hot climates	Applicable in all climates
4	Ventilation (indoor air quality)	100% Outside air	10 – 20% out side air Ammonia, Sulfur dioxide, CFC's
5	Toxicity	Non Toxic	Could be Toxic
6	Ozone Depletion	Eco Friendly	Contribute to ozone depletion
7	Maintenance	Very Low Maintenance	High Maintenance
8	Power consumption	100 W/Ton	1.2 KW/Ton.
9	Water consumption	High	Moderate

Table-5.3- A comparative study of evaporative cooling and Air Conditioning (3,7,8).

VI. ADVANTAGES OF EVAPORATIVE COOLING [9]

- Expected expenditure for installation is significantly low in comparison to refrigerated air conditioning.
- Expected expenditure of operation is 1/4 than of refrigerated air.
- Power utilization is limited to the fan and water pump. for the reason that the water vapor is not recycled, there is no compressor that utilized the majority of the power in closed-cycle refrigeration.
- The refrigerant is water. No particular refrigerants, such as CFCs, ammonia, or sulfur dioxide, are used that could be toxic, costly to replace, contribute to ozone depletion and/or be subject to stringent licensing and environmental regulations.
- Easiness in maintenance.
- The only two mechanical parts in the majority of basic evaporative coolers are the water pump and the fan motor, both of which can be repaired at low cost and often by a mechanically inclined homeowner.
- The constant and high volumetric flow rate of air improves the quality inside.
- Evaporative cooling increases humidity. In dry climates, this may get better comfort and decrease static electricity problems.
- The pad itself acts as a rather effective air filter when properly maintained; it is capable of removing a variety of contaminants in atmosphere, including city, ozone caused by greenhouse gasses, despite the consequences of very dry weather. Refrigeration-based cooling systems lose this capability whenever there is not enough humidity in the air to keep the evaporator wet while providing a constant trickle of condensate that washes out dissolved impurities removed from the air.

VII. RESULTS AND DISCUSSION

From the experiment it is obvious that reduction in temperature of 10 ºC from 45ºC to 35ºC DBT and reducing heat load through two evaporative coolers is equivalent to 5.2 tons. The total power required for providing this cooling is just 360 Watts which would be around 1.5 kW in case of normal air conditioner. The total water consumption rate of the coolers was 24 lit/hr. which can be easily afforded. The objective of the initial test program was to demonstrate the potential of this form of cooling. This is a significant achievement which reduces the heat load of bus by using evaporative cooling system. At 35ºC DBT& 44.7 % RH, people feel much comfortable than at 45ºC DBT and55% RH. By using this system arrangement we can save significantly on initial cost, running cost and maintenance cost thereby making the bus journey more comfortable. The concept of effective temperature which combines the effects of temperature, humidity and air motion is useful in design of evaporative cooling system. The larger difference between the wet bulb and dry bulb temperatures, the larger the feasible temperature drop.

VIII. CONCLUSION

The consequences of a comprehensive practical examination of evaporative cooling requirement for rural India have been accessible and discussed. therefore, mostly in India with diverse climatic environment would be likely to achieve an evaporative cooling performance on bus. The results confirm a foremost possible for the generation of evaporative cooling, which can be used to provide an effective cooling for modern bus by means of contemporary evaporation based sensible cooling systems. While the technique offers most potential in rural areas with temperate climate it has a significant potential to contribute to cool the bus during the summer and non-summer months and also at other times by means of cost and power saving. In order to take maximum advantage of the technique the bus needs to be designed to minimize solar and external heat gain and to separate the latent and sensible cooling functions.

By using this system, it is found that initial cost, running cost and maintenance cost are reduced and this would also make bus journey more comfortable. The concept of effective temperature which combines the effects of temperature, humidity and air motion is useful in design of evaporative cooling systems. The greater is the difference between the wet bulb and dry bulb temperatures, the greater is the achievable temperature reduction. It is concluded that the technique is particularly suited for conventional bus with stable and internally dominated sensible load patterns and hence long cooling seasons. This technology will be of help to the people and make their journey comfortable and happier.

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ABBREVIATIONS:

DBT = Dry Blub Temperature.
WBT = Wet Blub Temperature.
RH = Relative Humidity.
EAC = Evaporative Cooling System.
T.D = Ambient Temperature Difference.
T.D.S = Solar Temperature Difference.
K = Coefficient of Heat Transfer K cal/Hr./m²/ □C.
U = Coefficient of Heat Transfer for window due to solar heat gain.
G.D. = Grains Difference.