Review and experimental study on performance improvement of split air conditioner by reducing inlet air temperature to the ODU

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Abstract. Split Air Conditioners (ACs) are more commonly used now a days in residential and commercial buildings for achieving thermal comfort in all seasons. Split ACs work on well-known VCR (Vapour Compression Refrigeration) cycle. Split ACs used more in summer season and due to high outside temperature condenser pressure in a VCR cycle and ultimately result in high electricity consumption. One of the way to reduce energy consumption of Split ACs and increase cooling capacity is reduce air temperature entering to the condenser in ODU using evaporative cooling principle. In this paper detailed review have been carried out for the improvement of split air conditioner performance and experimental study conducted on Split AC (0.8 TR cooling capacity) with and without evaporative cooling pad at ODU. Evaporative cooling pad material and thickness have been varied to analyse their effects on cooling capacity and coefficient of performance (COP) of Split AC. Out of the PVC, Grass and Cellulose cooling pad of same thickness 150 mm, cellulose cooling pad at ODU of Split AC results about 2 bar reduction in condenser pressure and 1.5 KWH energy saving for 10 hours of operation in a day. Split AC with 100 mm thick cooling pad of cellulose material at ODU results in to approximately 16% increase in overall COP, 10.8 % increase in cooling capacity and 4.6 % reduction in power consumption and at 32°C DBT and about 35% RH outdoor weather condition.

1. Introduction
Energy plays a vital role in development and economic growth of any country. The increasing demand of energy with increasing population leads to research on energy conservation. Energy conservation is a key goal in all engineering fields. Nowadays split air conditioner are commonly used in residential and commercial buildings due to extreme high temperature weather condition, infrastructure development and due to improvement in quality of life of people. In developed countries, HVAC system consumes around 10% of total energy consumption, according to review on building energy consumption carried out by Lombard et al [1]. Split air conditioners works on VCR (vapor compression refrigeration) cycle with an air cooled condenser in an ODU (Outdoor Unit). Temperature of air-cooled condenser is directly depended on the ambient air temperature, therefore, in India in the region like Ahmedabad where in summer ambient air temperature remains very high, the condenser temperature and pressure increases considerably which consequently rises the power consumption of the air conditioner due to this increased pressure ratio. Increasing condenser temperature also decreases the cooling capacity of the VCR cycle due to the less liquid refrigerant mass entry in to the evaporator. These two effects decrease performance of air conditioner.
considerably at high ambient temperature in summer. In order to improve the performance of air conditioner in these situations, one of the way is to decrease inlet air temperature to the condenser. This reduces the pressure ratio across the compressor which results in reduction in power consumption and increase in cooling capacity and overall COP of the system.

A well-known method for decreasing inlet air temperature is to use evaporative cooling pad before the condenser coil. In this evaporative cooling system the water is sprayed on to the top of wetted medium and it cool the air passing through it, before reaching to the condenser. Evaporative cooling is a green method which does not involve any greenhouse emission and global warming [2]. Past research work on use of evaporative cooling principle to improve performance of air conditioning system is reviewed in next section.

2. Literature Review
According to Harby and et al. [3] using evaporative cooling principle, COP in air conditioning system with air cooled condenser can be improved by about 134% and power consumption can be reduced up to 58%. Detail literature review have been carried out in this project work and experiment set up and main findings of different researchers for improvement of air conditioning system using pre-cooling ambient air by evaporative cooling principle is presented in Table 1.

| Author/Year        | Method Used                  | Setup Details                                                                                                                                                                                                 | Main findings                                                                                   |
|--------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Ebrahim Hajidavalloo, 2007[4] | Experimental Investigation   | Two evaporative cooling pad with water injecting facility is used on two sides of window air conditioner to cool the air entering to the condenser.                                                      | They found reduction in power consumption by about 16% and increase in COP by 55% in window air conditioner with evaporative cooling pad in comparison to window air conditioner without evaporative cooling pad. |
| Ebrahim Hajidavalloo & Eghtedari, 2010[5] | Experimental Investigation   | An evaporative cooler was constructed and fixed to the existing air-cooled condenser of a split-air-conditioner.                                                                                           | They found that by using evaporative cooled air condenser, the power consumption can be reduced up to 20% and the COP can be improved around 50% in hot weather condition. |
| Martínez et al., 2016[6]   | Experimental Investigation   | A split air conditioner with R407C refrigerant charge have been used without and with cellulose evaporative cooling pad manufactured by Munters of 50 mm, 100 mm and 150 mm thickness. | Their experimental results indicate that Cellulose evaporative cooling pad of 100 mm thickness gives optimum performance and it reduces compressor power consumption by 11.4% the overall COP is increased by 10.6%. |
| Yang, Chan, Wu, Yang, & Zhang, 2012[7] | Experimental and Analytical Investigation | They used an institutional chiller plant comprising three similar screw chillers and experiments were carried out with water mist system to check the improvement in its efficiency. | Their result shows that chiller COP could be improved up to 18.6%, with the water mist system in chiller plant and also condensing temperature drop up to 7.2 °C. |
| Wen, Ho, 2010[8]            | Experimental investigation   | They use water curtains of                                                                                                                | Their found that out of six different...
| Authors                  | Type                  | Context                                                                 |
|-------------------------|-----------------------|-------------------------------------------------------------------------|
| Jang, & Yeh, 2014[8]    | Investigation         | six different types for precooling air entering to air cooled condenser. |
| Wang, Sheng, & Nnanna, 2014[9] | Experimental Investigation | Conventional refrigeration system with and without evaporative cooled condenser is used with R410A refrigerant. |
| Youbi-Idrissi, Macchi-Tejeda, Fournaison, & Guilpart, 2007[10] | Numerical Investigation | A semi-local numerical model of a sprayed air cooled condenser was developed and coupled to a simple refriger-ation system simulation. |
| Islam, Jahangeer, & Chua, 2015[11] | Experimental and Numerical Investigation | An experimental setup is fabricated by retrofitting a commercially available split air conditioner. Water is sprayed on condenser bare tubes. |
| Sarntichartsak & Thepa, 2013[12] | Experimental and Numerical Investigation | A split-type inverter-driven air conditioner with a rated cooling capacity of 3.5 kW with R-410A is used. An evaporative cooling system was built and installed with a condensing unit. |
| Yu & Chan, 2010[13] | Numerical Investigation | Air-cooled chiller system with mist pre-cooling have been used. |
| Sawan et al. 2014[14] | Experimental and Analytical Investigation | Split air conditioner drain have been used to pre-cool the inlet air to the condenser. |

A literature review revealed that however some work focused on the effect of pre-cooling air on the thermal behaviour of a refrigeration cycle is carried out, no references have been found in the literature which comprise the experimental study of evaporative cooling pad thickness and cooling pad material for Indian weather condition. The objective of this work is to study the performance of split ac with evaporative cooling pad at ODU and to determine optimum thickness and material of evaporative
cooling pad. For this purpose experiments are conducted on 0.8 TR capacity split air conditioner charge with R-22 refrigerant, where the condensing unit is modified by providing different material cooling pad with different thickness at air suction in ODU.

3. Experiment Setup Details

Experiment set up photograph and schematic diagram have been shown in Figure 1 and Figure 2 respectively. As shown in the photograph IDU of Split AC is fixed in a powder coated metallic frame with all necessary measuring instruments. In order to record suction and discharge pressure tapping have been made before and after compressor at suitable location. K-type thermocouple have been attached on copper tube before and after evaporator and condenser to give the temperature of the refrigerant at these points. Two energy meters have been used, one to measure power consumption from compressor and fan in IDU and ODU and one for measuring power consumption from pump. An anemometer and sling Psychrometer are used to measure velocity and DBT and WBT of air at inlet and outlet of IDU and ODU. Split AC test set up is charged with R-22 refrigerant and has rated capacity of 0.8 TR.

The evaporative cooling pad material of PVC, Cellulose and Grass (as shown in Figure 3) of 150 mm thickness and Cellulose cooling pad of 50 mm an 100 mm thickness have been used in project work. A separate water basin is kept below evaporative cooling pad and an 18 W pump is used for recirculation of water over evaporative cooling pad. Ambient air is precooled before it enter to the condenser in ODU by evaporative cooling principle. Split AC works on VCR cycle which is shown in schematic diagram. Refrigerant temperature and pressure and air temperature measurements are also shown in schematic diagram. Experiments are conducted on same set up with and without evaporative cooling pad of different thickness and type to study performance improvement of Split AC.

(a)  (b)

Figure 1. Photograph of experimental setup (a) IDU with control panel, (b) ODU with evaporative cooling pad
Figure 2. Experimental setup schematic diagram

Water at normal temperature is filled up in the sump below cooling pad during the experiment. Pump is kept submerged in water sump and to ensure steady state condition achieved set up is run for about 30 minutes prior to each reading. To ensure reliability of readings, each set of experiments is conducted for at least one hour and experiment with and without evaporative cooling pad of different thickness carried out on same day or under same outside whether condition. Bourdon tube pressure gauge manufactured by Wika Company is used to record compressor suction and discharge pressures. The temperature of refrigerant at salient points as shown in Figure 2 is recorded through multichannel digital temperature indicator. Sling Psychrometer is used to measure DBT and WBT of air at entry and exit of the IDU and ODU. RTD sensor is used to measure the temperature of air between the ODU and cooling pad. Lutron AM-4201 anemometer is used to measure velocity of air at the outlet of the ODU and IDU.

(a) (b) (c)

Figure 3. Photograph of evaporative cooling pad materials (a) Cellulose, (b) Grass, (c) PVC

4. Methodology

The effect of different cooling pad material and thickness on the overall performance of air conditioning system is experimentally determined by measuring the air flow rate and temperature at inlet and outlet of IDU, refrigerant temperatures and the energy consumption of the system including water circulation pump. For the analysis cooling capacity and total power consumption have been calculated using Eq. (1) and (2). For cooling capacity DBT and WBT at inlet and outlet of IDU and air velocity using anemometer is measured. Power consumption is measured using energy meter. Saturation efficiency of evaporative cooling pad and EER of system have been calculated using Eq.
(3) and (4). Saturation efficiency is defined as the ratio of the actual drop in temperature of air across the cooling pad to the wet bulb depression at entry of it. R-22 p-h diagram have been used to calculate theoretical COP of air conditioning system assuming simple saturated VCR cycle. Theoretical and actual COP are found using Eq. (5) and (6) respectively.

$$Q_c = m_{\text{air}}(h_1 - h_0)$$

Where,

$$m_{\text{air}} = \rho_a A_o C_o$$

$$P_{\text{net}} = W_c + W_f + W_p$$

$$\eta_s = \frac{t_1-t_0}{t_1-t_i}$$

Theoretical COP = \frac{h_1-h_4}{h_2-h_1} \quad (5)

Actual COP = \frac{Q_c}{P_{\text{net}}} \quad (6)

5. Experiment results and discussion

The experiment results without and with 150 mm thickness evaporative cooling pad of different materials, for R-22 vapour compression refrigeration cycle and air at different location in set up, is given in Table 2 and Table 3. Among the various material investigated cellulose evaporative cooling pad results in to maximum saturation efficiency as shown in Table 3. The experiment results without and with cellulose cooling pad of different thickness, for R-22 vapour compression refrigeration cycle and air at different location in set up, is given in Table 4 and Table 5. As shown in Table 5 cellulose cooling pad efficiency increases with increase in thickness of evaporative cooling pad.

**Table 2.** Experiment results for R-22 refrigeration cycle without cooling pad and with cooling pad of different material

| Test Condition | $P_s$ (bar) | $P_d$ (bar) | $T_1$ ($°C$) | $T_2$ ($°C$) | $T_3$ ($°C$) | $T_4$ ($°C$) | $h_1$ (kJ/kg) | $h_2$ (kJ/kg) | $h_3$ (kJ/kg) | Theoretical COP |
|----------------|------------|------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|----------------|
| Without EC Pad | 6.0        | 16.6       | 19.3         | 71.83        | 34.33        | 11.00        | 420.0        | 449.0        | 249.0        | 5.90           |
| With Cellulose EC Pad | 5.4        | 14.2       | 22.5         | 72.00        | 31.33        | 8.67         | 421.0        | 447.0        | 235.0        | 7.15           |
| With Grass EC Pad | 5.6        | 14.6       | 21.5         | 72.00        | 31.33        | 8.67         | 421.0        | 448.0        | 238.0        | 6.78           |
| With PVC EC Pad | 5.6        | 14.6       | 20.6         | 70.00        | 30.50        | 8.67         | 419.0        | 445.0        | 238.0        | 6.96           |

**Table 3.** Experiment results for air in set up without cooling pad and with cooling pad of different material

| Test Condition | Evaporator Inlet | Evaporator Outlet | $C_a$ (m/s) | $A_o$ (m²) | $\rho_a$ (kg/m³) | $Q_c$ (kW) | $P_{\text{net}}$ (kW) | Actual COP | $\eta_s$  |
|----------------|------------------|-------------------|--------------|-------------|------------------|------------|--------------------------|------------|----------|
| Without EC Pad | 31.0             | 19.8              | 13.4         | 12.2        | 2.0              | 0.052      | 1.22                     | 2.70       | 1.12     | 2.42 | 0          |
| With Cellulose EC Pad | 31.3             | 20.1              | 15.0         | 12.6        | 2.0              | 0.052      | 1.21                     | 2.74       | 0.99     | 2.76 | 93.84      |
| With Grass EC Pad | 31.8             | 19.8              | 14.4         | 12.2        | 2.0              | 0.052      | 1.21                     | 2.74       | 1.03     | 2.66 | 92.56      |
| With PVC EC Pad | 31.2             | 19.4              | 13.5         | 12.0        | 2.0              | 0.052      | 1.22                     | 2.72       | 1.01     | 2.68 | 91.68      |
Table 4. Experiment results for R-22 refrigeration cycle without cooling pad and with cellulose cooling pad of different thickness

| Test Condition       | P_s (bar) | P_d (bar) | T1 (°C) | T2 (°C) | T3 (°C) | T4 (°C) | h1 (kJ/kg) | h2 (kJ/kg) | h3 (kJ/kg) | Theoretical COP |
|----------------------|-----------|-----------|---------|---------|---------|---------|------------|------------|------------|-----------------|
| Without EC Pad       | 6.65      | 14.00     | 62.83   | 27.00   | 412.0   | 439.0   | 244.0      | 6.22       |
| 50 mm thick EC pad   | 6.57      | 14.12     | 57.50   | 23.33   | 411.0   | 436.0   | 240.0      | 6.84       |
| 100 mm thick EC Pad  | 6.17      | 13.87     | 65.50   | 6.83    | 417.0   | 442.0   | 238.0      | 7.16       |
| 150 mm thick EC Pad  | 6.26      | 13.76     | 62.83   | 7.00    | 416.5   | 441.0   | 237.0      | 7.33       |

Table 5. Experiment results for air in set up without cooling pad and with cellulose cooling pad of different thickness

| Test Condition       | Evaporator Inlet | Evaporator Outlet | C_o | L_o | ρ_a | Q_c | P_net | Actual COP | η_s |
|----------------------|------------------|-------------------|-----|-----|-----|-----|-------|------------|-----|
|                      | DBT(°C) | WBT(°C) | DBT(°C) | WBT(°C) | (m/s) | (m^2) | (kg/m^3) | (kW) | (kW) |                      |
| Without EC Pad       | 31.4    | 19.6    | 13.5    | 12.0    | 2.0   | 0.052 | 1.21    | 2.78 | 1.08 | 2.57                     | 0   |
| 50 mm thick EC pad   | 31.7    | 19.8    | 13.0    | 11.9    | 2.0   | 0.052 | 1.21    | 2.93 | 1.06 | 2.77                     | 73.4|
| 100 mm thick EC Pad  | 31.2    | 20.0    | 14.4    | 13.0    | 2.4   | 0.052 | 1.20    | 3.07 | 1.03 | 2.98                     | 82.22|
| 150 mm thick EC Pad  | 30.3    | 20.0    | 14.8    | 12.8    | 2.3   | 0.052 | 1.20    | 2.97 | 0.98 | 3.02                     | 90.31|

It is clear from Figure 4 and Figure 5 that use of evaporative cooling pad reduces discharge pressure of compressor due to lower inlet temperature of air at entry of condenser. Suction pressure to compressor is not significantly change as load on evaporator remain unchanged for all test condition.

Figure 4. Suction and discharge pressures of the VCR Cycle without cooling pad and with cooling pad of different materials
Figure 5. Suction and discharge pressures of VCR Cycle without cooling pad and with cellulose cooling pad of different thickness

Air temperature across the evaporative cooling pad and at exit of ODU are shown in Figure 6 and Figure 7 for evaporative cooling pad of 150 mm thickness and different material as well as cellulose cooling pad of different thickness. Tm is the temperature at exit of evaporative cooling pad, from Figure 6 and Figure 7 it is clear that evaporative cooling pad lowers the ambient air temperature which ultimately helps in reducing the refrigerant condensing pressure.

Figure 6. Air Temperature at various locations across the cooling pad of different materials
Figure 7. Air Temperature at various locations across the cellulose cooling pad of different thickness R-22 refrigerant temperature at evaporator and condenser inlet and outlet under different test condition shown in Figure 8 and Figure 9. Condenser outlet temperature and evaporator inlet temperature reduces in all experiments with evaporative cooling pad at ODU in comparison to without evaporative cooling pad at ODU.

Figure 8. Refrigerant Temperatures at various locations in VCR Cycle with and without cooling pad of different materials
Figure 9. Refrigerant Temperatures at various locations in VCR Cycle with and without cellulose cooling pad of different thickness

Net power consumption is measured using energy meters. During experiment with evaporative cooling pad pump power is consumed additionally, however it is found that decrease in compressor power due to reduction in pressure ratio is considerably higher than pump power requirement. This ultimately leads to reduction in net power consumption (refer Figure 10 and 11) with evaporative cooling pad in comparison to without evaporative cooling pad at ODU.

Figure 10. Net power consumption with and without cooling pad of different materials
In order to calculate theoretical COP of VCR cycle, R-22 pressure-enthalpy diagram have been used. Using suction and discharge pressure and refrigerant temperature at different location in air conditioning system theoretical COP is calculated using Eq. (5). Results have been shown in Figure 12 and Figure 13. Cellulose cooling pad of 150 mm thickness results in to higher theoretical COP compared to Grass and PVC cooling pad. Percentage improvement in theoretical COP decrease with increase in cellulose cooling pad thickness.

![Figure 11](image1.png)

**Figure 11.** Net power consumption with and without cellulose cooling pad of different thickness

![Figure 12](image2.png)

**Figure 12.** Net power consumption with and without cooling pad of different materials
In order to evaluate the performance of any air conditioning system, actual COP is a key parameter. The actual COP of split AC under different test condition is calculated using Eq. (6). The results shown in Figure 14 shows that cellulose material gives higher COP than Grass and PVC as found theoretically also. Figure 15 shows that actual COP increase from without evaporative cooling pad to 50 mm thickness evaporative cooling pad and 100 mm thickness evaporative cooling pad, however it not increases considerably with 150 mm evaporative cooling pad. This happens despite of higher saturation efficiency of 150 mm thickness cooling pad, as with higher cooling pad thickness airflow across the condenser decrease which reduces heat transfer in condenser.

Figure 13. Net power consumption with and without cellulose cooling pad of different thickness

Figure 14. Actual COP with and without cooling pad of different materials
6. Conclusions
Detailed review and experimental investigations have been carried out to study the energy saving potential of evaporative cooling pad coupled to ODU in Split AC. It is known fact that the COP of an air conditioner decreases with increasing ambient temperature. Particularly during summer season evaporative cooling pad at ODU shows promising as it not only reduce power consumption but increase cooling capacity also by reducing ambient air temperature entering to the condenser. Following conclusions have been drawn from this study:

- Out of the PVC, Grass and Cellulose cooling pad of same thickness 150 mm, cellulose cooling pad at ODU of Split AC results in reduction in condenser pressure up to about 2 bar and 1.5 KWH energy saving for 10 hours of operation of Split AC in a day.
- It is observed that actual COP increase significantly from 50 mm thickness evaporative cooling pad to 100 mm thickness, however percentage improvement are small as 150 mm thickness evaporative cooling pad is use.
- Split AC with cellulose cooling pad of 100 mm thickness at ODU results in to approximately 16% increase in overall COP, 10.8 % increase in cooling capacity and 4.6 % reduction in power consumption and at 32°C DBT and about 35% relative humidity outdoor air condition.

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Nomenclature
\[ P \] pressure (bar)
\[ T \] Temperature (°C)
\[ t \] dry bulb temperature of air (°C)
\[ t’ \] wet bulb temperature (°C)
\[ \dot{m}_{\text{air}} \] mass flow rate of air (kg/s)
\[ h \] enthalpy (kJ/kg)
\[ \rho_a \] density of air at IDU outlet (kg/ m³)
A_o area of IDU outlet (m²)
C_o velocity of air at IDU outlet (m/s)
Q_c Cooling capacity (kw)
P_{net} net power consumption (kw)
W power consumption (kw)
\eta_s saturation efficiency of evaporative cooling pad

Subscripts
s suction
d discharge
c compressor
f fan
p Pump
i inlet
o outlet
m middle
a air
r refrigerant
net net
1 compressor inlet
2 condenser inlet
3 capillary tube inlet
4 evaporator inlet

Abbreviations
COP Coefficient of Performance
TR Ton of refrigeration
ODU Outdoor Unit
IDU Indoor Unit
DBT Dry bulb temperature
WBT Wet bulb temperature
RH Relative humidity

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