



Energy Conservation in Window Air Conditioners

by **Dr. S. V. Kota Reddy**
Professor & Head
Dept. of Mechanical Engineering
Fr. C. Rodrigues Institute of Technology, Navi Mumbai

and **P. Gandhi, K. Nage, R. Pase, J. Wadke**
Students

Energy conservation in the use of air conditioning is being effected in many ways around the world. In government offices in Japan, officials are encouraged not to wear heavy suits during summer and space temperatures are raised by 1°C. In Italy, the health ministry has urged employers to allow their staff to dress in comfortable and airy casuals in summer. In India the BEE has devised star ratings for room ACs. This article studies the impact of TRIAC-based speed control in a window AC for varying air velocity over the occupants with a higher air temperature but similar feeling of comfort.

Concern for the environment and increasing price of energy requires reviewing conventional practices and developing novel alternatives for conserving energy. Human comfort is influenced by physiological factors determined by the rate of heat generation within the body and the rate of heat dissipation to the environment. Increased air speed over the body and clothing surfaces can increase convective and evaporative losses. Thus, even under conditions of high temperature and high humidity, discomfort can often be greatly reduced by increasing the air velocity. This article presents the

analysis of a modified window air conditioner with a TRIAC based speed control circuit for varying air velocity with respect to indoor air temperature. The various parameters like condenser, evaporator and indoor air temperatures; pressures at compressor suction and discharge, air velocity and power consumption were measured. Incorporation of the speed control systems has resulted in about 15% saving in energy.

What is Thermal Comfort Level?

Air conditioning refers to conditioning of air to maintain specific conditions of temperature, relative humidity, and low dust levels inside an enclosed space. Also it is

established that the same levels of human comfort can be achieved in an enclosed space at higher ambient temperatures [1].

Thermal comfort as per American Society of Heating Refrigerating and Air-conditioning Engineers

About the Author

Dr. S.V.K. Reddy has a doctorate in mechanical engineering from IIT Bombay and is engaged in teaching engineering subjects for the past 18 years. He is presently the secretary of ISHRAE Mumbai chapter and has been very active in various student activities organized by ISHRAE. He can be contacted on svk_reddy@hotmail.com

P. Gandhi, K. Nage, R. Pase and J. Wadke are all mechanical engineering students of Fr. C. Rodrigues Institute of Technology.

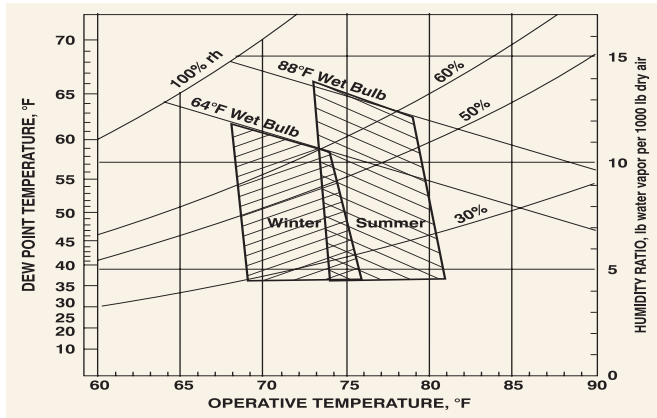


Figure 1: ASHRAE comfort zones [9]

(ASHRAE) 55-2004 approach [7] can be defined as "the condition of mind which expresses satisfaction with the thermal environment". There are in all six factors that have been identified as determining factors of the level of thermal comfort experienced. They are,

- a. Environmental Factors
 - Air temperature
 - Air speed
 - Humidity
 - Mean radiant temperature
- b. Individual Factors
 - Activity
 - Clothing insulation

Individual differences and recent thermal history also contribute to the level of comfort experienced by an individual that gives thermal comfort a subjective nature. The combined effects of environmental and individual factors can be represented on a psychrometric chart as shown in Figure 1.

A single parameter that takes into account all the factors and helps describe the level of thermal comfort or a comfort index is "Effective Temperature" (ET). As per ASHRAE

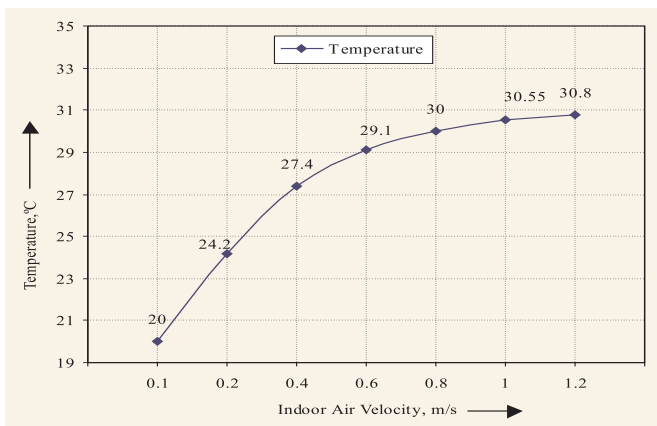


Figure 2 : Preferred air velocities at various air temperatures [6]. Discomfort can often be reduced by increasing air velocity.

55-1992 approach "Effective Temperature" can be described as "an arbitrary index, which combines into a single number the effect of dry-bulb temperature, humidity, and air motion on the sensation of warmth or coldness felt by the human body". The effective temperature is also a measure of feeling of warmth or coldness to the human body in response to the air temperature, moisture content, and air motion [2].

Thermal comfort depends on indoor air velocity. Ample research has been conducted to study the effect of variation in different parameters on the preferred indoor air temperatures to ensure same levels of thermal comfort, most notably by Fanger [6]. It has been discovered that :

a. Higher indoor air temperature requires greater indoor air velocities to provide thermal comfort as shown in Figure 2.

b. Variation of air velocity has greater influence on the preferred indoor temperature at lower air temperatures.

Increased air velocity increases the heat transfer from the body by reducing the thickness of air film adjacent to the body. The effect of increased air velocity is to increase the body heat loss and reduce the feeling of discomfort when the ambient air is at a temperature lower than body surface temperature [3].

The air-conditioner used for experimental analysis was an Onida make, model number W018GMIA [4]. The specifications of air conditioning unit were as follows:

- a. Power Consumption 1850Watts
- b. E. E. R 9.7 BTU/h-W
- c. Capacity 1.5 TR
- d. Running Current 8.8 A
- e. Power Supply 230 V
- f. Dimensions 435 mm x 660 mm x 745 mm (Height x Width x Depth)
- g. Compressor Reciprocating
- h. Control Mechanical

Modifications Made in Window Air Conditioner

To achieve energy conservation the conventional window air conditioner was modified as follows:

Motor

The original motor with a three-speed manual step control having 960 rpm was replaced with a higher capacity motor of 1440 rpm thereby providing for the possibility of having higher blower fan velocity.

Speed Control Circuit

Using the speed control circuit, the power to the blower motor was varied in accordance to the temperature of the return air. Return air temperature was an input parameter for the speed control circuit. The velocity of the blower motor was adjusted with respect to the variation in the return air temperature. This input was achieved through a thermistor which sensed the

continued on page 110

continued from page 108

temperature of the return air and gave a signal to the TRIAC, by the timer integrated circuit IC NE 555.

Measured Parameters

Various parameters like condenser, evaporator, indoor air temperatures, pressures at compressor suction and discharge, air velocity, and power consumption were measured in order to analyze the performance of the modified system.

Temperature

Temperatures at different locations of significance were measured using Chormel-Alumel type thermocouples and sling psychrometer. The locations at which the temperature was measured were:

- a. Evaporator inlet
- b. Evaporator outlet
- c. Condenser inlet
- d. Condenser outlet

The temperature range in which the condenser and the evaporator are operated have a bearing on the refrigerating effect achieved by effectiveness of heat transfer and also the overall coefficient of performance (COP). These temperatures are significant in establishing a relation between the temperature range and the overall COP of the system. These temperatures were sensed using thermocouples and displayed on the Multi Channel Temperature Indicator.

The dry bulb temperature (DBT) and the wet bulb temperature (WBT) of the return air as well as conditioned air were recorded so as to determine the refrigerating effect achieved on the air side. These temperatures were measured using sling psychrometers. These temperatures help to determine the enthalpy of the air being sent into the occupied space and that of the return air which in turn was used for determining the refrigerating effect achieved on the air side.

Pressure

The pressure variation at compressor inlet and outlet with respect to variation in the air velocity was studied. Refrigerant pressure at the suction and the discharge side of the compressor was measured using piezo-resistive pressure transmitters. The transmitters were used in a two-wire configuration [8] and the voltage output, calibrated in terms of pressure was displayed.

The pressures at the compressor inlet (suction pressure) and the compressor outlet (discharge pressure) were measured. The variation in velocity of air in response to the temperature variation causes variation in the operating pressures of the condenser and the evaporator. This has a bearing on the COP of the system as well as the life of the compressor. The specifications of the pressure transmitters used were as follows:

- | | |
|--------------------------|--------------------|
| a. Output | 4 to 20 mA |
| b. Excitation | 8 to 28V |
| c. Total accuracy | +/-0.5% full scale |
| d. Operating temperature | -25 to +80 °C |
| e. Weight | 60 g |

Air Velocity

The velocity of air sent into the room under the action of variable speed of the blower motor was measured using a turbine type vane anemometer at a distance of 1.22 m. The air velocity before modification was 2.22 m/s, which was increased to 3.45 m/s after modification. Air velocity was required to determine the refrigerating effect achieved by the system on the air side. Also the air velocity was used to determine the air distribution pattern in the room which in turn was needed to determine the level of thermal comfort experienced by an individual as a function of air motion. Specifications of the anemometer used were as follows:

- | | |
|-----------------------|---------------|
| a. Display | 18 mm LCD |
| b. Power Supply | 9 V DC |
| c. Series | AM 4201 |
| d. Range | 0.4 to 30 m/s |
| e. Operating Humidity | < 80% RH |
| f. Weight | 325 g |

Power Consumption

The power consumption by the system was measured using an energy meter. The energy meter was connected between the power supply and the switchboard used for the blower motor and the compressor. The energy meter used for the experiments had an energy meter constant of 750 revolutions per kW of power.

COP Calculations

The modified window air conditioner was installed in a room of size 8.2 m × 3.8 m × 2.4 m; in the centre of an exposed wall at a distance of 1 m from the floor. Incidentally, this is the ideal location for any window AC for the draft of cool air to cool a room uniformly. Having installed the experimental set up, observations under different conditions were made by following specific procedures. Initially the indoor conditions were DBT 29°C and WBT 24°C. First the blower motor was started and then the compressor. Simultaneously duration of the compressor on-off cycle as well as the time taken by the energy meter to complete 10 revolutions were measured using stop watches respectively. Also the different parameters i.e. suction and discharge pressure, refrigerant temperature at inlet and outlet to evaporator and condenser, DBT and WBT of return air as well as conditioned air, room temperature, ambient temperature were measured.

This procedure was performed for return air temperatures from 25 to 28°C under the above-mentioned ambient

continued on page 112

continued from page 110

conditions for a set of ten readings that is five on-off cycles of the compressor respectively. It was found that for the cut off temperatures from 25 to 28°C the conditioned air average RH increased from 80% to 81% and the return air average RH increased from 64.3% to 66%. At the same time as the return air cut-off temperature increased from 25 to 28°C the average air velocity of the blower fan increased from 1.9 m/s to 2.9 m/s and the energy meter reading increased from 85.7 s/10 rev to 92.1 s/10 rev.

The airside coefficient of performance of the air conditioner can be given as,

$$COP = \frac{\text{Heat removed from the room}}{\text{Compressor Work}} = \frac{Q}{W} \tag{1}$$

Knowing the inlet and outlet temperature of the air and plotting the same on the psychrometric chart, we can determine the corresponding enthalpies of air.

Knowing the density 'ρ' in kg/m³, the return air velocity 'v' in m/s and the effective cross sectional area 'A_c' in m², the mass flow rate can be determined.

$$m = \rho A_c v \tag{2}$$

Heat removed from the room is given as,

$$Q = [\rho A_c v (h_2 - h_1)] \cdot \sum t \tag{3}$$

Where,

h₁ and h₂ are enthalpies corresponding to inlet and outlet air temperatures respectively. The mass flow rate is calculated at the air outlet section of the window air conditioner.

t is the cycle time for recurring ON and OFF cycles.

Q is in kJ

Compressor work can be determined as,

$$W = \left(\frac{3600 \cdot n}{E_{nc} \cdot tn} \right) \cdot \sum t \tag{4}$$

Where,

W is in kJ

n = 10, number of revolutions on the energy meter

t is cycle time in seconds

tn is the time taken for 10 revolutions

E_{nc} = 750 is the energy meter constant in rev/kW h

Values of heat removed and work input were calculated over a period of 8 hours.

Results and Discussion

A series of experiments were conducted in the course of the project and results of prominence are illustrated in this section. In accordance with Figure 2, to achieve the same level of human comfort at a higher temperature, high

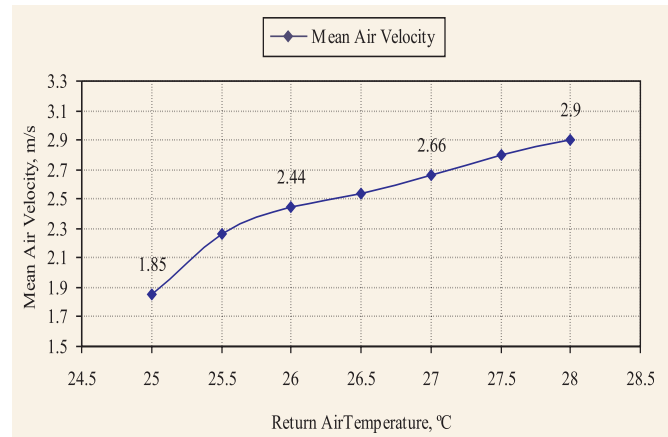


Figure 3: Variation of mean air velocity with respect to return air temperature (as per our experiment)

air velocity is required in the occupied space. A similar trend has been achieved, as cut off temperature increases the air velocity also increases as shown in Figure 3.

The most important finding of the experiments performed is that, under the modified conditions the operating pressure on the condenser side is lowered. This happens as the mass flow rate of air over the condenser coils is increased due to the blower motor rotating at a higher speed. At the same time the evaporator pressure is not very significantly altered. Hence, effectively, the operating pressure ratio is lowered. Also due to decrease in the condenser pressure, the refrigerating effect per kg of refrigerant increases. Variation of the suction and discharge pressure with respect to return air temperature is shown in Figure 4. The reduction in the operating pressure ratio contributes towards enhancing the operating life of the compressor as it is subjected to a lower pressure ratio.

Since the operating pressure ratio is lowered hence the power consumed by the compressor to compress the refrigerant from suction pressure to the discharge pressure is reduced. This reduction in compressor work leads to

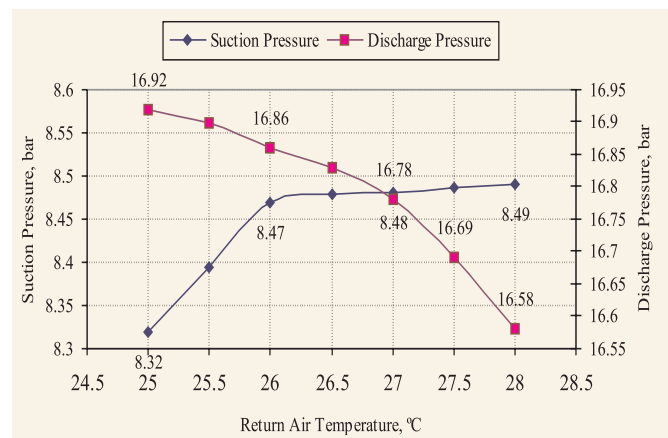


Figure 4: Variation of pressure with respect to return air temperature (as per our experiment)

continued on page 114

continued from page 112

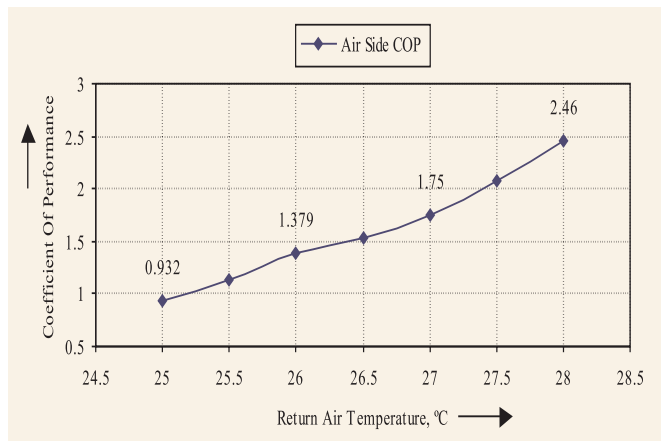


Figure 5: Variation of air side COP with respect to return air temperature (as per our experiment)

increase in COP of the system. Variation of air side COP of the system with respect to the return air temperature is shown in Figure 5.

The modified system demonstrated about 15% energy conservation compared with the conventional system. Calculations are shown in Table 1.

Sr. No	Parameter	Unmodified System	Modified System
1.	Return Air Temperature, °C	25	28
2.	Return Air RH, %	64.3	66
3.	Total Power Consumption by System, kWh	9.21	7.82
4.	Working hours per day, h	8	8
5.	Saving in power consumption in refrigeration, kWh	-	1.39
6.	Saving per day in refrigeration load, Rs./day	-	Rs.7/day
7.	Additional investment	-	Rs. 4500
8.	Percentage savings in power	-	15 %
9.	Simple payback period	-	1.75 years

Table 1: Comparison of various parameters between modified and unmodified system

The speed control circuit developed replaces the three-speed manual step control in the conventional window air-conditioner with an automatic ramp control. The circuit developed can be used to replace expensive automation technologies like variable frequency drives. (VFD).

Conclusion

The conventional window air-conditioner is modified by incorporating a speed control circuit which varies the speed of the blower motor with respect to return air temperature. There is a reduction in power consumed by the compressor since the indoor air temperature is maintained at a higher value. There is a small increase in power consumption of the blower motor due to increase in air velocity. However, the power saving in the compressor is much greater than the power consumed by the blower

motor. The modified system demonstrated about 15% energy conservation compared with the conventional system. The speed control circuit developed replaces the three-speed manual step control in the conventional window Air-conditioner with an automatic ramp control. Hence, it can replace expensive automation technologies like VFD. Appropriate thermal load considerations and ensured robustness of the system shall make this a highly economically viable technology for centralized air conditioning plants applications like malls and multiplexes.

Acknowledgement

We express our sincere thanks to Indian Society of Heating, Refrigerating and Air conditioning Engineers, (ISHRAE) Mumbai Chapter for giving the financial assistance to carry out this project at Fr. C. Rodrigues Institute of Technology, Vashi, Navi Mumbai.

We are also thankful to Prof. Sushil Thale, assistant professor, electrical engineering department, Fr. C. Rodrigues Institute of Technology for his valuable help in making the electronic circuits.

References

1. Dhar, P.L. 2001, How much cooling do we really need? In *Proceedings of International Conference on Emerging Technologies in Air Conditioning and Refrigeration*. New Delhi, India, 26-28 September. Delhi: Allied Publishers Pvt. Ltd.
2. Arora, S.C; and Domkundwar, S. 2000. *A course in Refrigeration and Air Conditioning*. Delhi: Dhanpat Rai and Co. (P) Ltd.
3. Reddy, S.V.K.; Chandramoulee, K.; Mundle Nandita; Rajesh Shreya; and Bhagat Tejas. 2004. Energy conservation in air conditioning, In *Proceedings of National Conference on Recent Advances in Mechanical Engineering*, Energy Section (EN), Paper No.: 4. Nashik, India, 16-17 January.
4. Chandramoulee, K.; Mundle Nandita; Rajesh Shreya; and Bhagat Tejas 2004, Energy conservation in window air conditioner. *Final Year Project Report*, University of Mumbai, Mumbai, India.
5. Reddy, S.V.K.; Chandramoulee, K.; Rajesh Shreya; Mundle Nandita; 2005, Automation in window air conditioner”, In *Proceedings of International Conference on Emerging Technologies in Intelligent System and Control*, Kumaraguru College of Engineering, Coimbatore, India. 5-7 January. Coimbatore: Allied Publishers Pvt. Ltd.
6. Wang Shan, K. 2001. *Handbook of Refrigeration and Air-Conditioning*. New York: Mc Graw Hill.
7. ergo.human.cornell.edu/ studentdownloads / DEA350pdfs / Thermcomfort.pdf
8. www.keller-druck.com
9. www.esmagazine.com/ES/FILES/IMAGES/ 3951.gfi