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Window Air Conditioner with Orthodox Refrigerants

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A B S T R A C T

The system design of window air conditioner does not evolve in one day. Due to the continous efforts are taken by the refrigeration and air conditionging professionals, successful and economic models of window air conditioners are currently used. This paper states about the development of window air conditioner with phase change material and water as refrigerants. Developed air conditioner was tested for its thermal performance achievement. Outcomes specify that thermal comfort acheivement was in satisfactory levels. Predicted mean vote and percentage of people dissatisfied values were calculated and the results were in the range of neutral to a slight cooling, according to Americal Society of Heating and Refrigeration and Air conditioning standard 55.

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NOMENCLATURE

M	Metabolic rate (W/m²)	q_{res}	Heat loss by respiration (W/m²)
l_{cl}	Clothing factor (m²C/W)	q_e	Heat loss by evaporation (W/m²)
t_{db}	Dry bulb temperature (°C)	q_c	Heat loss by diffusion (W/m²)
t_r	Radiant temperature (°C)	q_d	Heat loss by convection (W/m²)
v_a	Air velocity (m/s)	q_r	Heat loss by radiation (W/m²)
p_s	Vapour pressure (Pa)		

1. INTRODUCTION

Window air conditioners are the rudimentary model used across the world for comfort in buildings, but it has some drawbacks like noise in operation, use of CFC refrigerants, energy consumption etc. Air conditioning was once considered to be a luxury item in the buildings, but due to climate changes and thermal comfort requirements, air conditioning is a necessity in today's world. Modern world requires air conditioning products with less power consumption and good worth of life [1]. The weakening of the ozone layer owing to the release of chlorine from CFC and HCFC refrigerants has raised severe concerns about using them in vapor compression systems. Therefore, according to the revised version of Montreal protocol, CFCs were phased out by January 1996, except for essential users, and HCFCs are to be phased out by 2020 because of environmental concerns like global warming potential and depletion of ozone layer. The need to find substitutes for CFCs during the 1990s has led the refrigeration industry back to use hydrocarbons which have no impact on the ozone layer and insignificant contribution to global warming. Because of ecological problems such as ozone depletion and global warming, R22 needs to be phased out on a critical basis [2]. R22 was replaced by HCFC type of refrigerant Tetrafluoroethane [R-134 (a)] is having a global warming potential of 60%.

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In order to address this problem, an innovative model of window air conditioner design is proposed in this study. This model does not use a compressor and tube in tube type evaporator is used. Phase change material is filled in the tube and in the outer tube water is circulated with a help of a pump.

Thermal comfort study was done in the climatic conditions of Sultanate of Oman during summer months. For a solution to environmental impacts and cost-saving opportunities, designers and manufacturers turn to energy storage methods. One of the methods used to diminish energy consumption is thermal energy storage by phase change material.

2. LITERATURE REVIEW

The cooling capacity of window air conditioners ranges from 0.5 to 3 tons [3]. Since the window air conditioners are used for zone cooling nowadays, the energy intake by them has considerably increased. It was estimated that in the world market the yearly manufacture of unitary air-conditioners is about 33.7 million units. HCFC-22, which was used in window air conditioners has an ozone depletion rate of 0.055 and is controlled under the Montreal Protocol. It has to be phased out by 2030 in developed nations and 2040 in under developing nations [4].

Ministry of Regional Municipalities and Water Resources, Sultanate of Oman organized a workshop during July 2003, in partnership with United Nations Industrial Development Organization (UNIDO) and United Nations Environment (UNEP) to train the trainers to phase out the CFC's in Sultanate of Oman. In this workshop, it was sensed to review the use of refrigerants and the leeway of Hydrocarbons as refrigerants in refrigeration and air conditioning equipment. The need to find a capable substitute for CFC's has guided the refrigeration professionals to have a second thought to use hydrocarbons as refrigerants. Hydrocarbon mixtures provide an alternate venture to be used as refrigerants in refrigeration systems and they do not contain any halogen atom, are a promising substitute for CFC-12 and 22. Hydrocarbons are environmentally safe, proficient, and technologically reliable refrigerants and insulation foam-blowing agents and they are naturally occurring substances formed from fossilized plant matter and found throughout the world as oil and natural gas. Lower paraffin's such as propane, butane, and isobutene were successfully used as refrigerant before the dawn of chlorofluorocarbons**.** Hydrocarbons exist at a low price all over the world and are compatible with commonly used lubricants and materials of construction used in refrigeration systems. The main drawback of these refrigerants is their high inflammability, which has prohibited their use. But modern innovations have greatly improved the safety of hydrocarbon technologies. Besides due to very low charge of hydrocarbons (the amount of propane or butane in a domestic hydrocarbon refrigerator is only 40 to 60g equivalent to two to six cigarette lighters, depending on the size of the refrigerator) in small capacity refrigeration system inflammability does not present a problem. The present level of technological development and safety measures available have made it possible to use hydrocarbons as working fluids in domestic refrigerators.

The main motivation to adopt hydrocarbons in spite of their high inflammability is being eco-friendly. The hydrocarbons do not destroy the ozone layer and their global warming potentials are hundred times lower than that of CFCs and ten times lower than other CFC substitutes. Among hydrocarbon pure fluids, propane and isobutene are finding much attention as a substitute to CFC-12 in recent years. R-22, the popular refrigerant used in air conditioners, was replaced by HFC- 422a and HFC-417b by Llopis et al. [5]. The experimental results showed that, the mass flow rate of the refrigerants needs to be improved. R-22 was replaced by R-422 d by Aprea et al. [6]. The experimental results showed that the coefficient of performance (COP) of the system with R-422d showed 20% less compared to R-22 System and this is because of the high vapor density and low cooling capacity. Mixture of hydrocarbons, propane (R-290) and isobutane (R-600a) were among the main refrigerants, but due to the disadvantages like, flammability and safety purposes and the use is limited. In fact, the direction of the ongoing research is shifted to the safer refrigerants along with good environmental properties [7]. Study and analysis of hydrocarbon type of refrigerants showed less power consumption and less compressor work in comparison with tetrafluoroethane (R-134 (a)) [8]. As a representative from middle east countries, in association with Daikin, Kuwait is in the process of evaluating the refrigerant Difluoromethane [R-32] under high ambient temperature [1]. In buildings, phase change materials are used in three different ways for cooling and heating. 1) in building walls, 2) in other building components, other than walls such as floor and roof 3) phase change materials in heat and cold storage units [9]. The concept of free cooling was developed by Momeni et al. [10] by designing an air conditioning system with Calcium Chloride $CaCl_2$ as phase change materials (PCM) and air as heat transfer medium. Phase change materials were used in a thermoelectric refrigeration system by Riffat et al. [11]. Phase change materials were integrated with thermosiphons in the thermoelectric refrigeration system. The system showed improved performance.

Along with solar panels, PCM's plays a vital role in space heating. In 2005, S. Chen and M. Chiu [12] analyzed the solar heating system incorporated with phase change material. Heat from solar flat panel was transferred to water and the heat was transferred to the phase change material. Calcium Chloride with a melting point of 29° C was used as phase change material. The results displayed that, this system abridged the energy consumption by a maximum of 32%.

3. THERMAL COMFORT

Thermal comfort is a state of mind expressed by the occupants in a built environment. The driving forces of thermal comfort are temperature, relative humidity, mean radiant temperature and air velocity inside a closed environment [13]. Air temperature and relative humidity are the significant driving forces which determine thermal comfort [14]. Predicted mean vote (PMV) equation was proposed by Beizaee [15] and has been used as international standards. Apart from physical variables, personal variables such as personal clothing insulation of the occupant (clo), metabolic rate (met) are also taken into account for the predicted mean vote calculation.

3. 1. Estimation of Predictive Mean Vote and Percentage of People Dissatisfied The Predicted Mean Vote index gives a thermal reaction according to the psychophysical changes. To understand the concept of thermal comfort; it is general to analyze Fanger's PMV model [16]. In 1967, Fanger investigated that the human body undergoes physiological processes when it is close to the neutral. Predicted mean vote value is specified for seven sensations as per American Society of Heating and Refrigeration Engineers (ASHRAE) standard are as mentioned Table 1.

PPD (Predicted Percentage of Dissatisfied) index gives a quantifiable prediction of the number of people dissatisfied thermally. PMV is calculated by the following formula:

$$PMV = (0.303e^{-0.036M} + 0.0280)\{(M-W) - (q_c + q_r) - (q_d + q_e) - q_{res}\} \quad (1)$$

The connection between PMV and PPD is shown below and it is pragmatic that, even when the PMV is zero, 5% of the people are dissatisfied! The higher and lower limits of predicted mean vote are set at -0.5 < PMV < + 0.5, matching to a PPD < 10% which is called the acceptable indoor conditions.

TABLE 1. ASHRAE Standard 55 – Thermal Sensations

Point	Thermal Sensation
(+3)	Hot
(+2)	Warm
(+1)	Slightly Warm
(0)	Neutral
(-1)	Slightly Cool
(-2)	Cool
(-3)	Cold

Figure 1 shows the relationship between predictive mean vote and percentage of people dissatisfied. Recommended values of the factors for the calculations of the predicted mean vote are shown in Table 2.

Percentage of dissatisfied people can be calculated as follows:

$$PPD = (100 - 95)e^{-(0.03353\times PMV^4 + 0.2179\times PMV^2)} \quad (2)$$

Then the comfort temperature is calculated as follows:

$$t_{comfort} = [33.5 - 3l_{cl} - \left(\frac{M}{A}\right)(0.08 + 0.05l_{cl})] \quad (3)$$

4. RESEARCH METHODOLOGY

4. 1. Design of Window Air Conditioner The negative points of window air conditioner include noise in operation and the use of CFC and HCFC refrigerants. In this model, a tube-in-tube type evaporator with aluminum fins was designed. Fins in forced convection situations are used for increasing heat transfer from and mechanical components to drive away excess heat from the source. Heat transfer coefficient of a structure depends on the thickness and material selection. This design comprised of ½" OD copper is used for outer pipe and ¼" OD copper pipe is used as the inner pipe. In the outer tube phase, change material was filled and water is circulated in the inner tube. A 24 V DC motor operated pump is used to circulate the water through the tube-in-

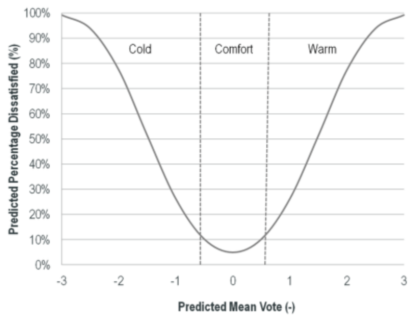

Figure 1. Relationship between predictive mean vote and percentage of people dissatisfied

TABLE 2. Recommendations for Predicted Mean Vote

Factor	Symbol	Recommended Value
Metabolic rate	M	46-232 W/m²
Clothing factor	l_{cl}	0-0.310 m²C/W
Dry bulb temperature	t_{db}	10-40 °C
Radiant temperature	t_r	10-40 °C
Air velocity	v_a	0-1 m/s
Vapour pressure	p_s	0-2700 Pa

tube evaporator. Water outlet from the evaporator is then circulated through the condenser for heat removal. Water is a natural fluid which do not harm environment, and can be suitable replacement chloroflourocarbons in some refrigeration applications. Since water has good thermal properties and easily available, it is suitable to mix with chemicals and used in vapor absorption systems [17]. Double shaft motor as present in the conventional type window air conditioners is used to circulate the blower air through the evaporator coil and to have airflow over the condenser. Double heat pipe bsed heat exchangers were designed and tested for satisfactory performance by Ahmadzadehtalatapeh and Yahu [18]. Figure 2 shows the schematic design of evapofrator.
Compressor and direr were not used in the system, because there is no refrigerant circulation through the system. The compressor was replaced with a water pump which circulated water between evaporator and condenser. Mean radiant temperature in the room is calculated as follows:

$$MRT = \frac{T_1A_1+T_2A_{2+\cdots+}T_{nA_n}}{A_{1+}A_{2+\cdots A_n}} \quad (4)$$

where, MRT represents mean radiant temperature, Fp-n is angle factor between person and surface and A is the surface area.

This window AC was fixed in a room with dimensions ten feet by ten feet. Temperature, relative humidity, air velocity were measured and the values are shown in Figure 3.

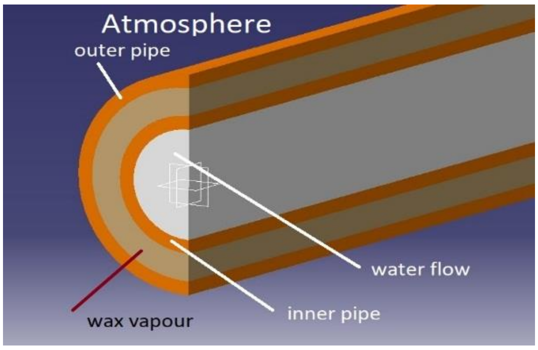

Figure 2. Evaporator Design

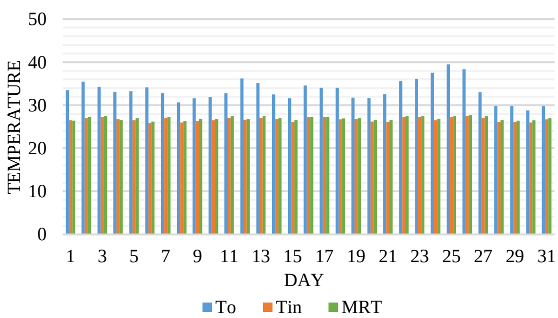

Figure 3. Temperature Measurement

4. 2. Phase Change Material Paraffin wax was used phase change material, which is a bi-product from the petroleum refining process. Properties of paraffin wax are: Paraffin wax is a mixture of saturated aliphatic hydrocarbons (C_nH_{2n+2}). The chemical formula of Paraffin Wax is $C_{25}H_{52}$. The main characteristics of wax are: (1) colourless (2) odourless (3) translucence and (4) melting point at 45° C (5) electrical insulator (6) heat of fusion is 200 kJ/kg to 220 kJ/kg K (7) Heat capacity is 2500 J/kg K.

4. 3. Response Surface Methodology Response Surface Methodology (RSM) is a grouping of statistical and optimization approaches that can be used to model and optimize proposals. In this study, RSM and Box-Behnken Design were applied to get the optimization and interaction between the four significant variables as listed below. The ranges were carefully chosen from the actual measurements from the indoor environment of the room. Interaction between the parameters in calculating PMV values is given below in Equation (5).

$$PMV = (-154.26775) + (0.242708 \times Temperature) + (0.301742 \times RH) + (51.48263 \times Air\ Speed) + (9.71645 \times MRT) - (0.010774 \times RH \times MRT) - (2.14286 \times Air\ Speed \times MRT) + (4.46307 \times Air\ Speed^2) - (0.156366 \times MRT^2) \quad (5)$$

The ranges of thermal comfort parameters are shown in the below-mentioned Table 3.

Analysis of variance (ANOVA) was used for the graphical study of the data to define the relations between the process variables and responses achieved. The model terms are evaluated base on the P-value (Probability) analogous to a 95% confidence level. Total 29 runs were completed to study the interactions between the four self-governing variables are reflected in each run to examine the strength of thermal comfort using predicted mean vote – the percentage of people dissatisfied model.

5. RESULTS

5. 1. Predicted Mean Vote (PMV) PMV values calculated for the month of July 2017 is shown in Figure 4. The predicted mean value lies between neutral and slight cooling, which is considered to be satisfactory level.

TABLE 3. Range of Factors Selected for Response Surface Methodology

Parameter	Units	Type	Low	High
Temperature	Degree	Factor	25.9	27.5
RH	Percentage	Factor	50.2	68.1
Air Speed	M/s	Factor	0.1	0.3
MRT	Degree	Factor	26.2	27.6

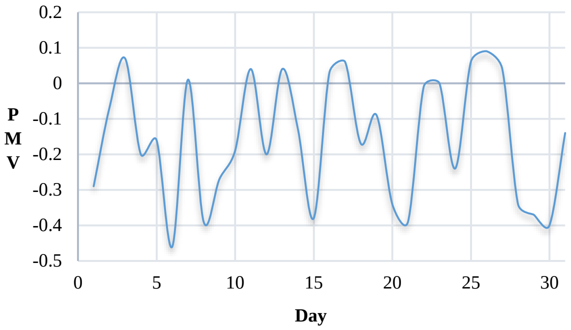

Figure 4. Predicted Mean Vote (PMV)

5. 2. Percentage of People Dissatisfied (PPD)

Percentage of people dissatisfied was found to be around 5 persons. This value is considered to be satisfactory as per ASHRAE standard 55 on thermal comfort. Figure 5 shows the percentage of people dissatisfied values conferring to the respective predictive mean vote values.

Figure 6 depicts PMV versus PPD. Table 4 presents the ANOVA regression parameters for the expected response surface quadratic models and other statistical parameters of thermal comfort analysis. The percentages of people dissatisfied are shown in Figures 7 and 8.

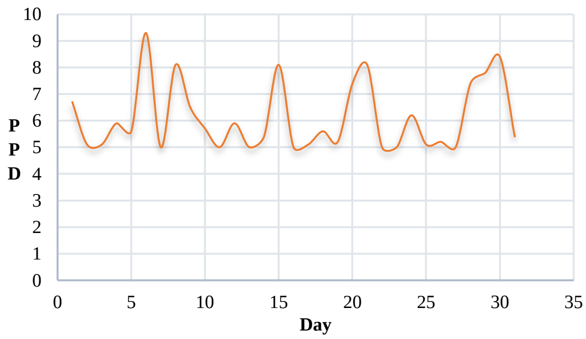

Figure 5. Percentage of People Dissatisfied (PPD)

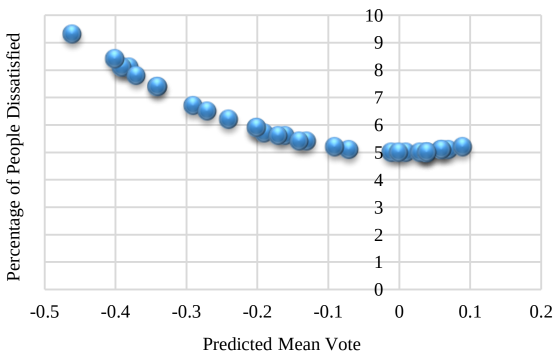

Figure 6. PMV Vs PPD

TABLE 4. ANOVA for Reduced Quadratic Model (Response 1: PMV)

Source	(ΣSqs)	Df	Mn.sq	F	P	Sig
Model	3.39	8	0.4237	109.99	<0.0001	Y
A-Tem	0.45	1	0.45	117.4	<0.0001	
B-RH	0.1365	1	0.1365	35.45	<0.0001	
C-Air	2.30	1	2.30	596.30	<0.0001	
D-MRT	0.33	1	0.333	86.54	<0.0001	
BD	0.0182	1	0.182	4.73	0.0418	
CD	0.090	1	0.090	23.37	0.0001	
C^2	0.0137	1	0.0137	3.57	0.0734	
D^2	0.0405	1	0.0405	10.52	0.0041	
Residual	0.0770	20	0.0039			
Lack of fit	0.0655	16	0.0041	1.42	0.3989	N
Pure Error	0.0115	4	0.0029			
Cor Toral	3.47	28				

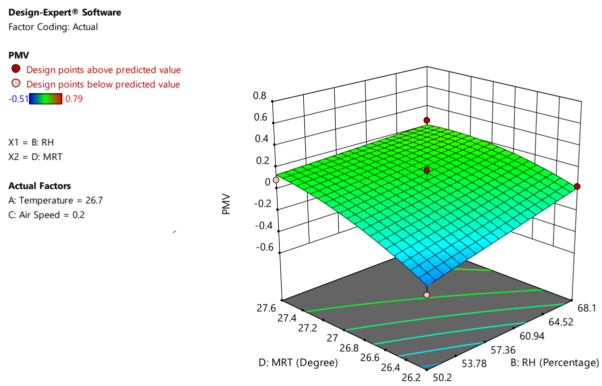

Figure 7. Percentage of people Dissatisfied

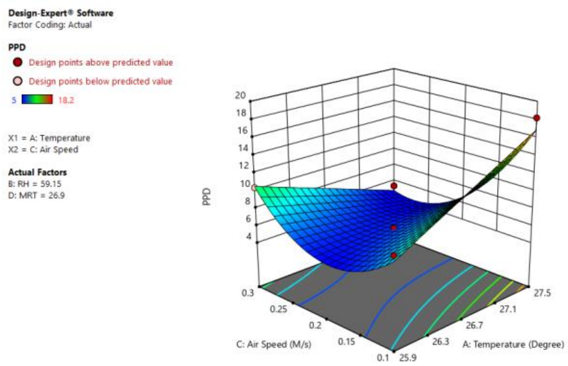

Figure 8. Percentage of people Dissatisfied

6. CONCLUSIONS

Thermal comfort achieved by the window air conditioner using phase change material and water as refrigerants was found to be satisfactory. The RSM model shows that, Predicted mean vote [PMV] ranges from +0.15 to -0.5.

Percentage of people dissatisfied [PPD] ranges around 5. From this result, it is concluded that thermal comfort lies in the satisfactory comfort level as given by ASRAE Standard 55. The quadratic model developed by using response surface methodology significant and the factors like relative humidity, mean radiant temperature and air velocity has an impact on thermal comfort. The combination of hydrocarbons and water as refrigerants in larger capacity air conditioning systems to be studied for their performance and thermal comfort achievement should be initiated for the successful performance and thermal comfort achievement.

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چکیده

طراحی سیستم تهویه هوا پنجره‌ای در یک روز تکامل نمی‌یافته است. با توجه به تلاش‌های مستمر توسط متخصصان تهویه مطبوع و تهویه مطبوع، مدل‌های موفق و اقتصادی تهویه هوا پنجره در حال حاضر استفاده می‌شود. این مقاله در مورد توسعه تهویه مطبوع پنجره با مواد تغییر فاز و آب به عنوان مبردها بیان می‌کند. تهویه مطبوع طراحی شده برای دستیابی به عملکرد حرارتی آن آزمایش شده است. نتایج حاکی از آن است که دسترسی به گرما در سطح رضایت بخش بوده است. طبق استاندارد جامعه استاندارد گرمایش و تبرید آمریکایی و استاندارد تهویه مطبوع ۵۵، پیش‌بینی میانگین رای و درصد از ارزش‌های ناراضی مردم محاسبه شد و نتایج در محدوده خنثی به خنک‌کننده خفیف محاسبه شد.

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