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"Performance Evaluation of Human Powered Air Conditioning System"

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ABSTRACT: Human power is the earlier source of power. In present work use of human power is demonstrated to work as a prime mover to Vapour Compression Refrigeration (VCR) system to drive its compressor. A system is designed which is known as Human Powered Air Conditioning System (HPACS) which uses pedal power from bicycle to supply power to compressor with the help of chain drive mechanism. This system may be helpful for the people living in re-mote areas; those are suffering from non-availability of electricity, frequent power cuts for extended period of time. This system may help those peoples by providing cooled air in extreme summer conditions which uses their own efforts, also help them for their physical fitness. Performance of HPACS is evaluated by considering various aspects of air conditioning.

KEYWORDS: Human Power, Pedal Power, VCR (Vapour Compression Refrigeration), HPACS (Human Power Air Conditioning System), COP (Coefficient of Performance), DBT (Dry Bulb Temperature), WBT (Wet Bulb Temperature), RPM (Revolutions Per Minute)

I. INTRODUCTION TO HUMAN POWER AND AIR CONDITIONING

Technological advancements are producing more and more advanced and luxurious system to ease the life for the peoples living in the urban side of many developing countries. But on the other hand peoples from the rural side are facing with several problem like non availability of electricity, power cuts, unemployment etc. further in the modern life style to keep ourselves physically fit everyone is working out on treadmills at expense of human energy which could be used otherwise. Further all the advanced and luxurious system are operated by either electrical energy or fossil fuels which are presently running out. For all these problems use of human muscle can be a good alternative to fulfill the energy requirements for various applications and which are associated with their daily activities. Hence keeping these things in mind many of the human powered machines such as chaff cutter, flourmill, brick making machine, forge hammer etc. are developed in last few decades. Bicycle is still the cheapest mode of transportation is the best and very first application of the pedal power technology. The present work demonstrates the study of power availability from human efforts, finding best suitable technique to use human power, checking for feasibility to use human power for VCR system, which may be helpful for providing cool air in remote areas suffering from scarcity or load shedding of electricity.

1.1 Human Power

Human beings are very adaptable and can produce power over a wide range of pedaling speeds. However, people can produce more power or the same amount of power for a longer time if they pedal at a certain rate. This rate varies from person to person depending on their physical condition. A simple rule is that most people engaged in delivering power continuously for an hour or more will be most efficient when pedaling in the range of 50- 70 revolutions per minute (rpm).

1.2 Vapor Compression Refrigeration

Air conditioning (often referred to as AC, A.C., or A/C) is the process of removing heat from a confined space, thus cooling the air, and removing humidity. Air conditioning can be used in both domestic and commercial environments. This process is used to achieve a more comfortable interior environment, typically for humans or animals; however, air conditioning is also used to cool/dehumidify rooms filled with heat-producing electronic devices, such as computer servers, power amplifiers, and even to display and store artwork.

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Vapor Compression Refrigeration or vapor-compression refrigeration system (VCRS), in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

Refrigeration may be defined as lowering the temperature of an enclosed space by re-moving heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

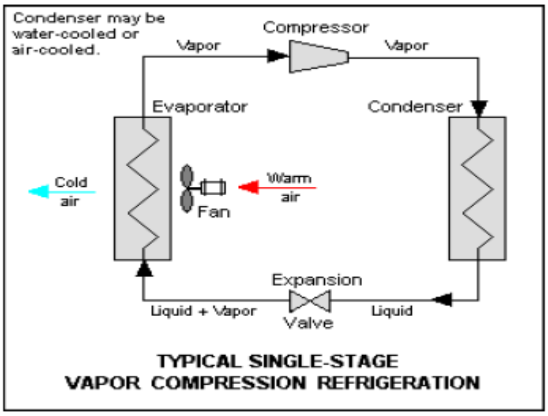

Fig.1 Vapour Compression Refrigeration System

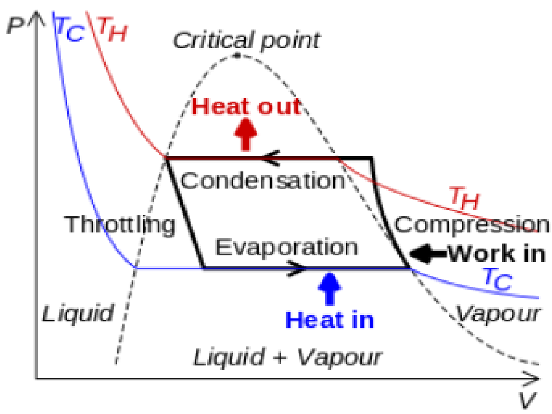

Fig.2 P V Diagram for VCR Cycle

Figure 1 depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is com-pressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case). Following figure shows the PV diagram for VCR cycle.

II. LITERATURE REVIEW

The scholars in the technical field have carried out work on improvement aspect of human powered equipment. There is increasing demand for energy. Therefore, extensive research has been done to harness energy from human power and to predict the performance of different type of mechanisms to use human power effectively. This section presents a summary of the fundamental as well as the state-of-the art research that has been conducted in the area of human power equipment modelling and performance prediction.

David Gordan Wilson focused on understanding Pedal Power. He concluded in his work that the person can develop near about 75 W to 200W of power with peddling. Most people engaged in developing power continuously for extended period of time will be most efficient when their peddling is in the range of 50 to 70 rpm's. Pedal power can be used for very low power applications such as sewing machines with approximately 100% transmission efficiency at all working conditions and for high power applications such as irrigation pump by using standard high gear arrangement with almost 90% power transmission efficiency.

J.P. Modak and S.D. Moghe described about design and development of a human powered machine for the manufacture of lime flyash sand bricks.

Kajogbola R. Ajao et. al. represented design and development of pedal powered soap mixer.

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Prasad A. Hatwalne et al highlighted the design and development of pedal operated flour mill.

Umesh Bokade et. al. provided solution for design and development of manually energized water distillation device.

P. B. Khope and J.P. Modak addressed the development and performance of a human powered flywheel motor (HPFM) operated forged cutter.

Sharad Kumar Chandrakar et al fabricated and experimentally studied a human powered mechanical device, for battery charging.

Sharad Kumar Chandrakar et al- In this paper authors experimentally studied the animal powered electrical generation system for home lighting.

Stefan Mocanu et al explained an energy scavenging system built with recycled and independent components and targeted at the energy consumed while exercising was presented.

R.N. Dehankar et al presented the exhaustive survey on the flywheel motor focusing on the work done so far. Hence a new setup human powered flywheel machine introduced for paper corrugation.

Prasad Hatwalne et al summarized maximum technical information about the human powered mechanism which could help the researchers for development of Human powered mechanism (HPM) for their purpose.

M.P. Mohurle et al- investigated importance of human power as an alternative energy source.

Akhilesh A. Nimje et al focused attention of researchers to find an economically viable alternative for harnessing energy with the help of available resources to improve the quality of life in remote areas. This work proposed a pedal powered generator with energy storage that can be utilized to light a bulb and a small fan even during non-pedaling period.

Thierry Kazazian and Arjen Jansen presented the relation between eco design and human-powered products.

III. EXPERIMENTATION

The material congregated in literature review is processed and firstly cooling load estimation is to be carried out by considering specified required condition. After finding out total cooling load and considering cooling capacity of conventional AC using electrical or any other non-renewable sources of energy as prime mover for compressor, comparison is done whether the HPACS can able to satisfy the cooling requirement of assumed condition of cooling. Once it is clear that human power can be satisfy considered cooling requirement. Then next step is to find power required for compressor which comprises of its rotations and torque as well. After this, selection of proper mechanism is adopted which can be able to transmit human power by bicycle pedaling up to compressor so that power requirement of compressor can be fulfilled. It decided to plan and proceed with swash-plate compressor for its power requirement since it is most suitable compressor for proposed HPACS and necessary instruments for measurement of important temperatures of air inside conditioned place and temperature on various points on the HPACS are selected. Also pressures of condenser and evaporator are measured with the help of Bourdon's tube pressure gauges. The only criterion for the selection of compressor is the minimum for requirement hence the swash plate type compressor of make Subros Model SLA 4 is selected since it require only 360 watt power for compressor as given is the catalogue of respective manufacture.

Fig.3 Experimental Setup

Fig.4 Chain Drive connecting with Compressor

Fig.5Condenser Fin tube type condenser

Condenser Fan: Working on 12v DC supply and Blower: working on 12v DC supply above mentioned component uses power from battery which can be charge with the help of dynamo which rotates with the wheel of bicycle. But in present work for their working external battery supply I used to avoid power loss in pedaling so that maximum power should be applied to compressor.

Temperature sensor Arrangement:

Four no. thermocouple and an indicator set is used for temperature measurement, the thermocouple can able to detect positive as well as negative temperature. Bourdons tube pressure Gauges are used for measuring condenser and evaporator pressure are used which can present in terms of psi unit. Sling pshychrometer is used for measuring DBT and WBT through of the experimental procedure, representing the temp in temperature in ºC.

Experimental Procedure:

The detailed procedure of performance of the test and it involves several parameters and methods adopted for measurement of important parameters as per the plan are given below.

a) Measurement of DBT and WBT of Conditioned Room:

b) Pedal rotation:

c) Condenser and Evaporator Pressure:

d) HPAC System temperatures:

The plan for experimental procedure is to pedal bicycle with the help of persons with different weight so that variety of HPACS can be analysis at different input conditions. So, persons having following weights pedaled the present bicycle for 50 minute at 20 rpm, 30 rpm and 40 rpm. Temperature readings (DBT and WBT) after each 10 minute are measured.

Following figure shows the experimental setup

Person no.	Weight in kg	Person no.	Weight in kg
1	49	6	59
2	50	7	61
3	51	8	63
4	53	9	67
5	56	10	70

Table 1: Persons of different weight selected for experiment

The observations are recorded after performing the measurement of important operating parameters of the experimental setup at selected location as per the procedure specified during the experimental work. Experimentation is also done by changing pedaling rotation as 20 rpm, 30 rpm and 40 rpm by 10 persons having different weight. So that they will apply different valued force on pedal according to their capacity and we can able to analyze the performance of HPACS at varied rate of input power at 3 different revolution rate refer tables

Sr. No.	Time	20 rpm		30 rpm		40 rpm	
	(hour)	DBT	WBT	DBT	WBT	DBT	WBT
1	0 min	30	23	30	23	30	23
2	10 min	29.5	23	29.5	23	29.5	22.5
3	20 min	29.5	22.5	29.5	22.5	29	22
4	30 min	29	22.5	29	22.5	29	21.5
5	40 min	29	22	28.5	22	28.5	21.5
6	50 min	28.5	21.5	28.5	21.5	28.5	21

Condenser pressure	145 psi	150psi	155 psi
Evaporator Pressure	60 psi	65 psi	70 psi
Mass Flow Rate	1LPM	2 LPM	3 LPM

Table 2: Experimental observations of test conducted for pedaling person having weight 49 kg

By adopting the same procedure tests are conducted for pedaling following weights of person having weight 50 kg, 51 kg, 53 kg, 56 kg, 59 kg, 61 kg, 63 kg, 67 kg and 70 kg.

The performance prediction of HPACS still mainly depends on an accurate estimation of the basic DBT, WDT of conditioned space, mass of air present in the room and the heat gained by room air from surrounding. Room air is continuously recirculates in the conditioned room with the help of blower for the duration of 50 minutes test is conducted in which heat is removed by refrigerant R134a circulating inside the evaporator coil which results into lowering DBT, WBT of room air. Then to evaluate the performance of sys-tem, rate of change in DBT, WBT, Actual COP of HPACS and theoretical COP for given temperature and pressure conditioned is calculated. For the same mathematical model has been used for following cases:

1) Calculation of Actual COP of HPACS

2) Calculation of Theoretical COP

Heat gain by room air by various elements Heat transfer rate through glass window

$= A_{(GLASS)} (U_{GLASS} * \Delta T)$

$= (1.06*0.91)(3.25*4)$

= 12 watt

Where,

$A_{(GLASS)}$ =area of glass window in m^2

U_{GLASS}=overall heat transfer coefficient in $W/m^2.K$ through glass.

ΔT= Temp. Difference (T_2-T_1)

T_2 = Temp outside the room

T_1= temp inside the room

Heat transfer rate through door

$= A_{(door)} \times (U_{door} \times \Delta T)$

$=1.16*3.25*4 = 15$ watt

$A_{(door)}$ = area of wooden door in m^2

U_{wood}= overall heat transfer coefficient in $W/m^2.K$ through wood

Heat transfer rate through roof

$= A_{roof} \times (U_{roof} \times \Delta T)$

$= 11.81 \times (1.316 \times 7)$

= 62 watt

A_{roof} = area of concrete roof in m^2

$U_{concrete}$ = overall heat transfer coefficient in W/m^2K through concrete.

Heat Transfer by tube light = 36 watt

Total heat gain by air from various elements

= 12+15+62+36 = 125 watt.

Sample calculation for Actual COP:

This sample calculation is done for observation from Table: 2

When person with 49 kg weight pedal at 20 rpm

Considering initial DBT = 30 ^{0}C = 303 K and WBT = 23 ^{0}C

$q_{cooling} = m (h_1-h_2)$

$m = \rho_{air} \times V_{air}$

V_{air} = volume of room = 10×10×12 = 33.98 m^3

$$\rho_{air} = \frac{P}{R \times T} = \frac{101.325}{0.287 \times 303} = 1.165 \frac{kg}{m^3}$$

$$m = \rho \times V = 1.165 \times 33.98 = 39.58\ kg$$

Considering above mass of air to be remain constant for all the calculations since the air is recirculating into room during test period and the initial temp. Condition is also similar as gone through all initial DBT, WBT observations.

From psychometric chart

h_1= 68.5 kJ/kg

h_2= 63 kJ/kg

$$q_{cooling} = m \times (h_1 - h_2) = 39.58 \times (68.5 - 63) = 217.69\ kJ$$

$$q_{cooling} = \frac{q_{cooling}}{Duration\ of\ test\ in\ Seconds} = \frac{217.69 \times 1000}{50 \times 60} = 72\ watt$$

Total Cooling Effect = 72 + Q_T = 72 + 125 =197 Watt

$$\text{Actual COP} = \frac{Total\ Cooling\ Effect}{Compressor\ power}$$

Compressor Power = 0.90 × Pedal Power

= 0.90 × 200 = 180 Watt

$$\text{Actual COP} = \frac{197}{180} = 1.09$$

Calculation of Theoretical COP

$$COP_{th} = \frac{Refrigerating\ Effect}{Compressor\ Power} = \frac{(h_1 - h_4)}{(h_2 - h_1)} = \frac{(253-106)}{(273-253)} = 7.35$$

(Values of h_1, h_2, h_4 are taken from P-h Chart by plotting cycle upon it)

Similarly pedal power supplied by operator in following way [1]

Sr. No .of Person	Weight In (Kg)	Considered Pedal Power Supply	Power Available At Compressor Considering 90 % Efficiency Of Chain Drive (Watt)
1	49	200	180
2	50	205	185
3	51	210	189
4	53	220	198
5	56	235	211.5
6	59	250	225
7	61	260	234
8	63	270	243
9	67	280	252
10	70	300	270

Table 3: Shows actual power available at Compressor

Results

Table 4: Results for actual COP of HPACS

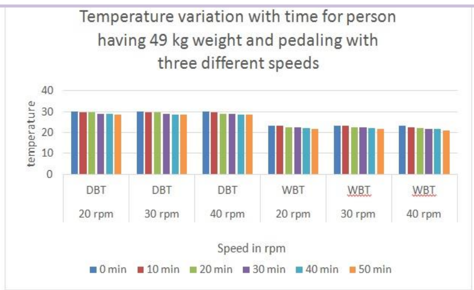
Sr. No.	Weight of Person	Pedal Speed (RPM)	Cooling Effect (W)	Input Power to Compressor (W)	Actual COP For HPACS
1	49	20	197	180	1.09
		30	197	180	1.09
		40	218	180	1.2
2	50	20	204.16	185	1.1
		30	210.75	185	1.13
		40	217.35	185	1.17
3	51	20	223.95	189	1.18
		30	230.54	189	1.22
		40	237.14	189	1.25
4	53	20	223.95	198	1.13
		30	230.54	198	1.16
		40	237.14	198	1.19
5	56	20	243.74	211.5	1.15
		30	250.33	211.5	1.18
		40	256.33	211.5	1.21
6	59	20	250.33	225	1.11
		30	256.93	225	1.14
		40	263.53	225	1.17
7	61	20	263.53	234	1.12
		30	270.12	234	1.15
		40	276.72	234	1.18
8	63	20	283.32	243	1.16
		30	289.91	243	1.19
		40	296.5	243	1.2
9	67	20	296.53	261	1.13
		30	303.11	261	1.16
		40	309.7	261	1.18
10	70	20	332.9	270	1.19
		30	336.09	270	1.24
		40	335	270	1.31

Table 5: Results Table for theoretical COP

Sr. No.	Weight of Person (kg)	Pedal Speed (rpm)	h_1 (KJ/kg)	h_2 (KJ/kg)	h_4 (KJ/kg)	Theoretical COP
1	49	20	253	273	106	7.35
		30	256	276	106	7.5
		40	258	276	106	8.44
2	50	20	254	273	106	7.35
		30	256	276	106	7.5
		40	258	276	106	8.44
3	51	20	255	273	106	7.35
		30	256	276	106	7.5
		40	258	276	106	8.44
4	53	20	253	273	106	8.35
		30	256	276	106	7.5
		40	258	276	106	8.44
5	56	20	254	273	106	7.05
		30	256	273	106	8.82
		40	258	273	107	10.06
6	59	20	254	273	106	7.05
		30	256	273	106	8.82
		40	258	273	107	10.06
7	61	20	254	273	106	7.05
		30	256	273	106	8.82
		40	258	273	107	10.06
8	63	20	253	277	109	6
		30	256	277	108	7.04
		40	258	276	109	8.27
9	67	20	253	277	109	6
		30	256	277	108	7.04
		40	258	276	109	8.27
10	70	20	253	277	109	6
		30	256	277	108	7.04
		40	258	276	109	8.27

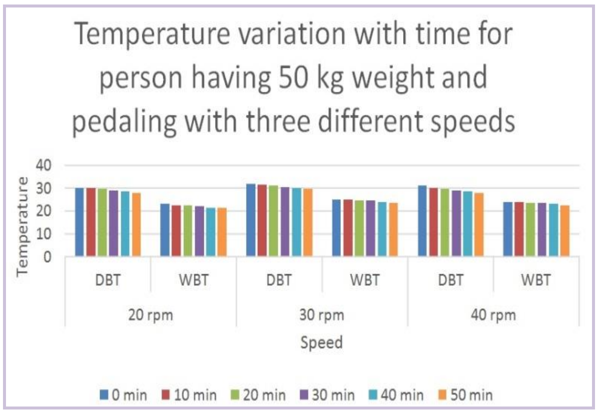
From above result tables it is observed that time required to decrease DBT and WBT is less as speed of compressor is more. Actual COP of HPACS depends upon weight of peddler and hence on effort applied during pedaling.

Figure 6 to 15: The graphs showing the variation of temperatures (DBT and WBT) with respect to speed and time for 10 peddlers having different weights.



The graph shows the variation of temperatures (DBT and WBT) with respect to time, for person having 49 kg weight and pedaling with different speed an. From the graph it is observed that time required to decrease DBT and WBT is less as speed of compressor increases.

Figure 6



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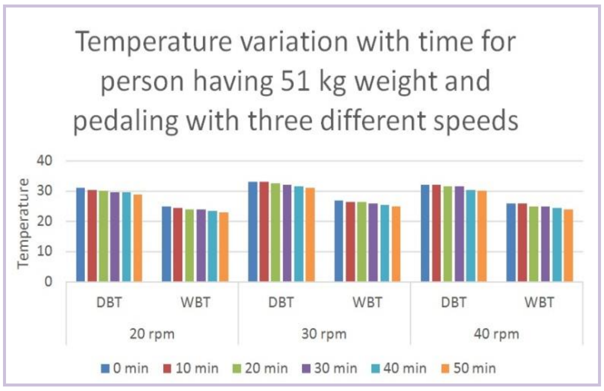

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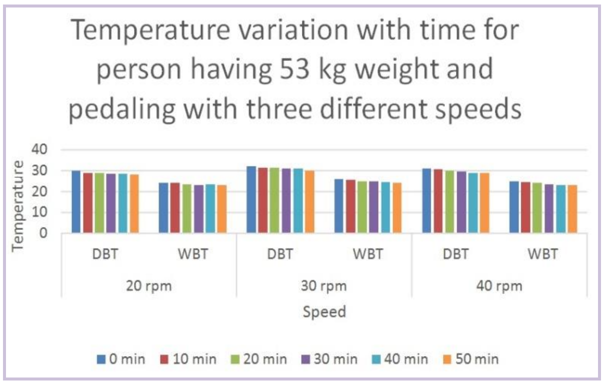

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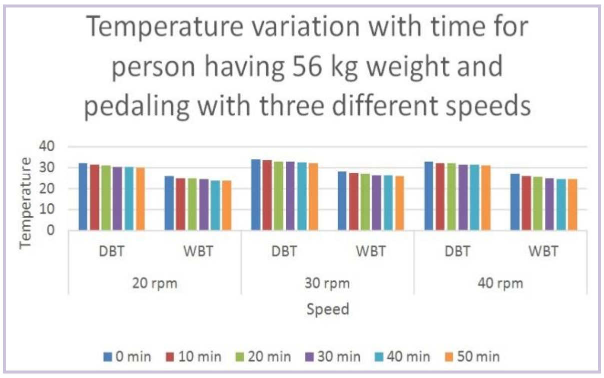

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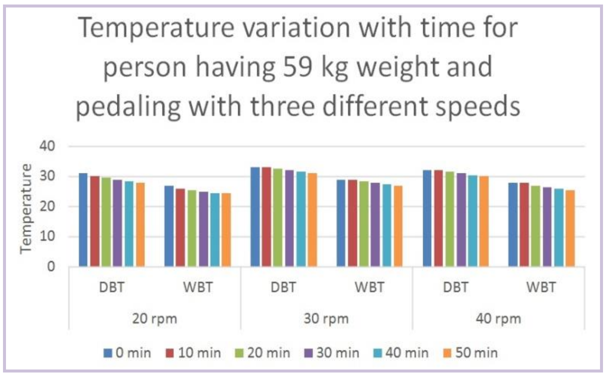

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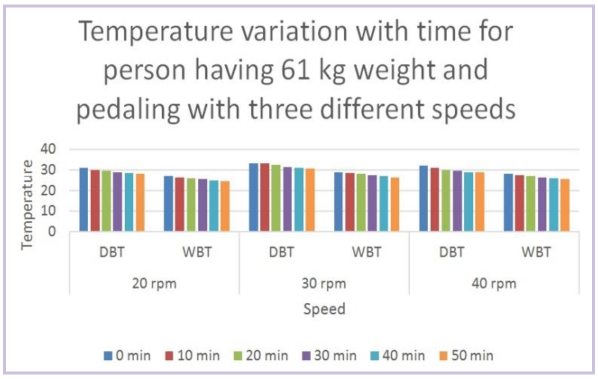

Figure 12

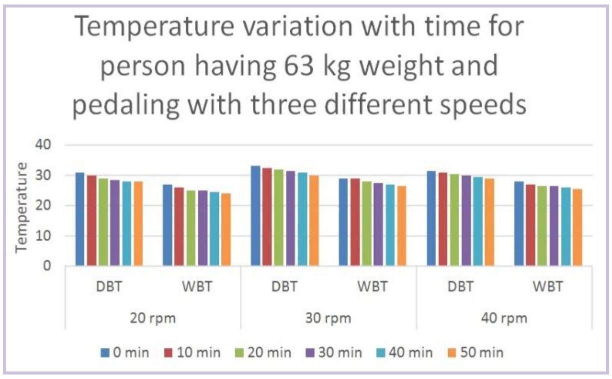

Figure 13

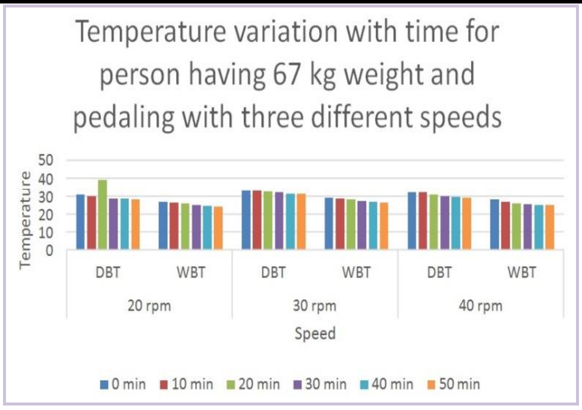

Figure 14

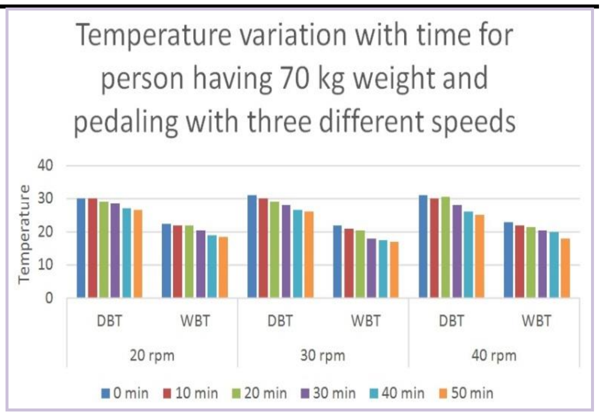

Figure 15

Figure 16: Shows the graph of Actual COP for HPACS with weight of person and speed

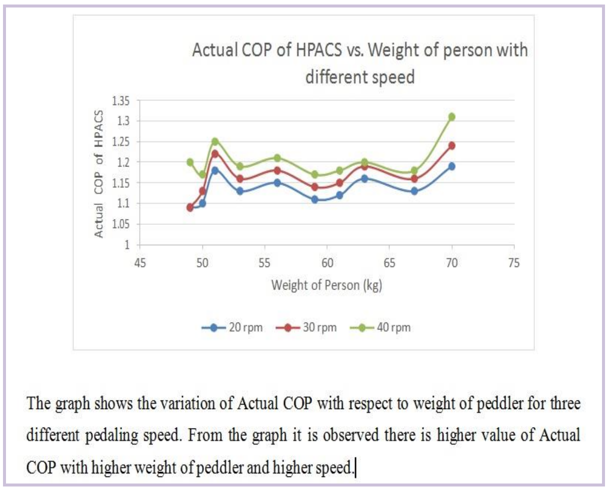

Fig.16 Shows the graph of Actual COP for HPACS with weight of person and speed

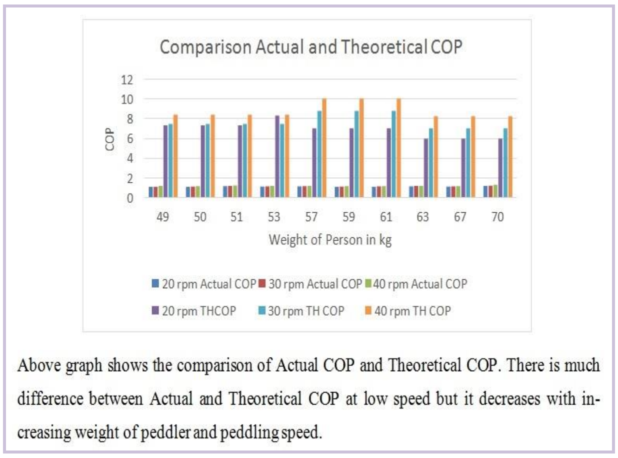

Fig.17 Shows the graph for Comparision Actual COP to Theoretical COP

IV. CONCLUSION

From experimentation of HPACS it is observed that Human Power can be feasible for Vapor Compression Refrigeration System. Though there is too much difference between actual and theoretical COP for the system, it is near to conventional VCR air conditioning system those provides COP in the range of 3. This system can be helpful for remote places where problem of electricity is severe. Also it may be used at Gymnasium where effort of human during cycling is used to compress the refrigerant in compressor. After experimentation it is found that for HPACS COP varies from 1.09 to 1.32. COP depends on weight of person used for pedaling and speed of rotation.

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