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Design and Experimentation of Roll Bond Evaporator for Room Air Conditioner with R-22 as Refrigerant

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ABSTRACT

The world is looking towards producing products which consume less power without compromising on quality of life. The increase in use of refrigeration and air conditioning appliances are contributing to global warming. The world wide temperatures are shooting up at an increasing rate. This paper presents a design of roll bond evaporator as the heat exchanger to provide cooling in room air conditioner. Presently all room air conditioners use tube and fin evaporators. This study presents roll bond evaporator as a power saving alternative to tube and fin evaporator. The experimentation has been done and comparative study of roll bond evaporator with that of tube and fin evaporator is presented. It was found out that while the tube and fin evaporator took 30 minutes to get a uniform temperature of 25 ºC in the room, the roll bond evaporator took only 25 minutes to get that uniform temperature, thereby saving 5 minutes of running of air conditioner.

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NOMENCLATURE

A	Area	u	Velocity (m/s)
D_h	Hydraulic diameter	v	Specific volume (m^3/kg)
f	Friction factor, Fanning number	P	Pressure (N/m^2)
h	Specific enthalpy, Convective heat transfer coefficient (kJ/kg, W/m^2K	q	Heat transferred (kJ)
h_{fg}	Latent heat (kJ/kg)	**Greek Symbols**	
m	Mass flow rate	ρ	Density (kg/m^3)
g	Gravity(m/s^2)	Δx	Change in dryness fraction
Nu	Nusselt's number	ν	Kinematic viscosity (m^2/s)
Re	Reynolds number	μ	Dynamic viscosity (Ns/m^2)
Pr	Prandtl Number	**Subscripts**	
K	Thermal conductivity (W/mK)	l	liquid
		f	fluid

1. INTRODUCTION

There is an alarming rise in temperature globally. The global surface temperature in February 2016 is 1.35° C warmer than the average temperature for the month during the earlier years. To beat the heat, people are indiscriminately using refrigeration and air conditioning appliances. They are steadily contributing to increase in energy consumption. Along with naturally varying climate, human-induced warming is making living uncomfortable.

The refrigerants which are used in these applications cause ozone depletion and global warming. The Montreal Protocol and Kyoto protocol has definitely made the world to look at the refrigerants which are eco-friendly. A complete phase out of ozone depleting,

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CFC refrigerants was possible with untiring effort of every country. The refrigerant which is presently being used in room air conditioners is R-22 ($CHClF_2$). This is a HCFC refrigerant, and has to be phased out. Research is going on to develop products which are eco-friendly, without compromising on human comfort. Development of power saving- green product which provides the same/better degree of comfort will be definitely a win-win situation.

1. 1. Motivation for the Research The primary aim of this paper/research is to present a solution to reduce power consumption in a room air conditioner. The present day room air conditioners use tube and fin evaporators for providing the desired cooling rate. The tube and fin evaporators are actually bare tube evaporators which are covered with fins. The refrigerant enters into the evaporator tubes predominantly in liquid form, and air moves over the tubes. The fins on the evaporator tubes increase the contact surface and increase the heat transfer. The distribution of conditioned air in a room by using tube and fin evaporator is not uniform. The area which is directly in front of the evaporator will be rapidly cooled, whereas the other regions will be cooled very slowly. This creates different cooling zones in a single room. It results in running of AC system for a longer period of time to get uniform temperature. Hence power consumption also increases.

To reduce power consumption, an alternate evaporator, roll bond evaporator is proposed for room air conditioner. The roll bond evaporator is fabricated by rolling together two panels of aluminium by applying pressure and heat during the rolling process such that the two sheets are welded together into a single sheet. By applying weld stop coating in a serpentine pattern, an un-welded region will be created. Figure 1 shows sketch of roll bond evaporator and Figure 2 shows the cross section at A-A. Presently the roll bond evaporator is limited to refrigerator. Roll bond evaporator gives uniform cooling in a room. It gives uniform temp at different planes in the room. This eliminates different temperature zones and helps in achieving uniform temperature in the room at less time. Hence power consumption decreases.

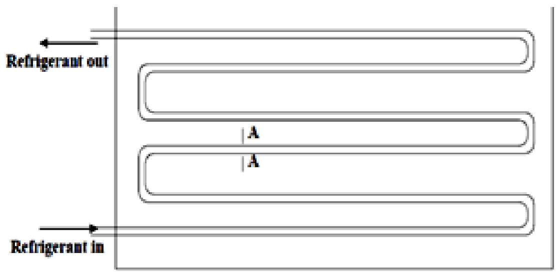

Figure 1. Sketch of Roll Bond Evaporator

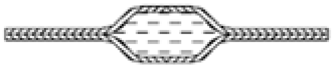

Figure 2. Cross-section of Roll Bond Evaporator at A-A

In this paper, roll bond evaporator is designed for refrigerant R-22, at different design conditions.

2. LITERATURE SURVEY

The available literature shows that if proper design modifications are done, the roll bond evaporator can be used as heat exchanger in many of the applications. The literature given below shows the suitability of roll bond evaporator as a heat exchanger. Luigi [1] experimented with different materials having different thicknesses for a roll bond evaporator. They have found that the performance of refrigerator increases by 5.3% when raw or annealed aluminium protective sheet of thickness 40 – 350 microns is used over cooling coil. Roberto [2] in his invention, stated that refrigerant circuit becomes simpler if the evaporator is manufactured with roll bond technique. Cesaroni and Fulton [3] have used a roll bond panel for an automotive heat shield to protect the occupants from heat developed from exhaust systems. Patel et al. [4] has used a roll bond panel for cooling of a computer sub system. The panel gave him maximum cooling. Anderson et al. [5], Pierre [6] Chawla [7], Lavin and Young [8], Dembi et al. [9], Dhar [10], Kern [11], Piert and Isbin [12] have given various correlations for refrigerants R-12 and R-22 in both single phase and two phase heat transfer applications. They have covered a wide range of applications: from horizontal tube to vertical tube, from bare tube to tube and fin. P. S. Ravi et al. [13] have developed procedure for finding inside heat transfer coefficient. Two phase correlations were used to find the heat transfer coefficient. P.S. Ravi et al. [14] have published a paper, giving details of design of a roll bond evaporator for a room air conditioner using R-22 as refrigerant under one design condition. Ahmadzadehtalatapeh and Yau [15] in their experimental work used a double heat pipe based heat exchanger in an air conditioning system. They have found that these heat exchangers are superior in terms of energy savings. Fazel et al. [16] in their investigation on pool boiling heat transfer have used different correlations for finding pool boiling heat transfer coefficient. They have conducted experiments using water/amines solutions and verified the values. Prashant, Singh and Sarao [17] have done experimental investigations to find out the heat transfer characteristics and friction factor of water based Al_2O_3 nanofluids as a coolant in brazed plate heat exchanger. It was found that use of nanofluids in a plate heat exchanger has increased heat transfer upto 34%. Ziapour and Rahimi

[18] developed a FORTRAN code for estimating the entropy production due to the natural convection heat transfer in a cosine wavy absorber solar collector. The simulation results were compared with a flat plate absorber. It was found that with increasing of the cosine wave amplitude, the collector enclosure irreversibility decreases.

The above literature survey suggests that better results are possible if a roll bond evaporator is used for a room air conditioner.

3. DESIGN OF ROLL BOND EVAPORATOR WITH R-22 AS REFRIGERANT

The design procedure for roll bond evaporator has been established by P. S. Ravi et al. in their publication [13]. In this paper the design is carried out by taking temperature of refrigerant in condenser as 40ºC. The design is repeated by taking the temperature of refrigerant in condenser as 35 ºC.

3. 1. Design Parameters A Room air conditioner of 1 ½ TR capacity has been chosen for designing roll bond evaporator, with condenser at 40ºC. The temperatures of roll bond evaporators was taken as 0°C, 5°C, 10°C and 15°C. The outside diameter of roll bond evaporator tube is 0.0127 m. The plate is taken as BWG 14. The expected value of overall heat transfer coefficient is calculated to be 17.78 W/m^{2}K [14]. The design is carried out again by taking temperature of condenser as 35 ºC.

3. 2. Design of roll Bond Evaporator, with Condenser Temperature at 40°C and Roll Bond Evaporator at 0°C.

Calculation for (Refrigerant side) Inside Heat Transfer Coefficient:
Basic calculations are done with reference to the basic refrigeration cycle with no superheating and no sub cooling. From Refrigerant R-22 properties, enthalpies of refrigerant before compressor is 405.361kJ/kg and the enthalpy of refrigerant before entry of evaporator is 249.684 kJ/kg. Its calculated mass flow rate is m = 0.03337 kg/s.

Initially, inside heat transfer coefficient of refrigerant is calculated by considering the flow to be in single phase from Dittus Boelter correlation.

Dittus Boelter Equation:
Nusselt's number, Nu = 0.023 $Re^{0.8}$ $Pr^{0.4}$, Nusselt's number is given by Nu = (h d)/k. For the present calculations, Pr=3.146, Re $_D$= 20,855.22 and L/D=623, all of which are in valid range. The heat transfer coefficient so calculated for R-22 is 1149.72 W/m^{2}K.

The refrigerant is predominantly in two phase while flowing through roll bond evaporator. The inside heat transfer coefficient for two phase is found out by the following correlations [14].

(i) Spitter, Parker, Quinston Correlation.
$(h D/k) = C_1\{ [GD/\mu_L]^2 [J \Delta x\, h_{fg}\, g_c/(L g)] \}^{0.4}$
where D is inside diameter of the tube, $C_1 = 8.2 \times 10^{-3}$, G = m/A , Δx = difference in quality of refrigerant, h_{fg} enthalpy of evaporation, L length of evaporator, g_c for SI system is 1 and g acceleration due to gravity.

(ii) Bio-Pierre correlation for complete evaporation:
This correlation considers complete evaporation of refrigerant with 5 to 7K of super heat.
$Nu_m = 0.0082 (Re_f^{\,2}\, k_f)^{0.4}$,
k_f is load factor = $(\Delta x\, h_{fg})/L$

(iii) Two phase Chato- Wattelet correlation
$h_{tp} = h_1[4.3 + 0.4 (Bo.\ 10^4)^{1.3}]$, h_1 is from single phase correlation and Dittus Boelter correlation is considered.
$Bo = q''/(G\, h_{fg})$, $q''=q/A$

(iv) Chaddock correlation
$h_{tp}= 1.85\, h [Bo \times 10^4 + (1/ H_{tt})^{0.67}]^{0.6}$, where $H_{tt} = [(1-x)/x]^{0.9} \times (\rho_g/\rho_f)^{0.5} (\mu_f/\mu_g)^{0.1}$

(v) Bogdanov correlation
$h = [Z^2 G^{0.4} \Delta T]/d$. The value of Z is given from the data book and is 1.46.

(vi) Chato/Dobson correlation
$h_{tp} = f(\chi_{tt}) \{[\rho_L (\rho_L- \rho_v) g\ h_{fg}\, k_l^3]/[d\, \Delta T\, \mu_L]\}^{0.25}$
where $f(\chi_{tt}) = 3.75 /(\chi_{tt})^{0.23}$
$\chi_{tt} = [(1-x)/x]^{0.9} \times (\rho_g/\rho_f)^{0.5} (\mu_f/\mu_g)^{0.1}$

(vii) Chaddock Brunemann's correlation
$h_{tp} = 1.91\, h [Bo\ 10^4 + 1.5 (1/ \chi_{tt})^{0.67}]^{0.6}$
The values of heat transfer coefficients so obtained from calculations for the above correlations are 1886.56W/m^{2}K, 4981.06 W/m^{2}K, 2836.67 W/m^{2}K, 4338 W/m^{2}K, 3859.7 W/m^{2}K, 3952.7 W/m^{2}K and 3867.8 W/m^{2}K, respectively. The average value of inside heat transfer coefficient for two phase flow is obtained as 3674.78 W/m^{2}K.

Calculation for Air side (Outside) Heat transfer coefficient: The air side heat transfer coefficient is found out by the following correlations [14].

(i) Mc Quiston, Spitter & Parker- First correlation
St $Pr^{2/3}$ = J factor
where St is Stanton number and J factor is obtained from the graph given by Spitter. It is a function of J_p, where J_p is given by $J_p = Re_D^{-0.4} (A/A_t)^{-0.15}$, QA is Total

heat transfer area (outside area of roll bond evaporator), and A_t bare tube area of roll bond evaporator (without fins).

(ii) Mc Quiston, Spitter & Parker -Second correlation

J factor = $0.0014 + 0.2618\ Re^{-0.4}(A/A_t)^{-0.15}$

(iii) Correlation given in heat transfer data book

$Nu = 0.117\ Re^{0.65}\ Pr^{(1/3)}$, for $0.75<Pr<16700$ and $Re >10{,}000$, Nusselt's number is based on hydraulic diameter, $D_h = (4A/P)$. For the geometry of roll bond evaporator, $D_h = 0.1167$.

(iv) Correlation given in Engineering Science data unit

$Nu = a\ Re^m\ Pr^{0.34}$ $a= 0.211$ and $m = 0.651$

(v) Briggs & Young correlation

$Nu = 0.134\ Re^{0.681}\ Pr^{(1/3)}$

(vi) Correlation given in heat transfer data book, based on film temperature and hydraulic diameter

$Nu = 0.25\ Re^{0.6}\ Pr^{0.38}$

For $1.2 <Pr<250$ and $Re >10{,}000$

(vii) Correlation from heat transfer data book (considering all modes of heat transfer)

$h_{total} = h_{convection} + h_{diffusion} + h_{radiation}$,

calculation of $h_{convection}$ is based on

$Nu = 0.193\ Re^{0.618}\ Pr^{1/3}$

calculation of $h_{diffusion}$: $h_{diffusion}/ h_{convection} = 0.1$, $h_{radiation}$ is fixed as 2.5 W/m^2K

The values of air side heat transfer coefficients obtained from calculations by the above relations are 25.1 W/m^2K, 24.52 W/m^2K, 15.82 W/m^2K, 28.74 W/m^2K, 24.73 W/m^2K, 20.29 W/m^2K and 23.449 W/m^2K, respectively. The average value of air side heat transfer coefficient so obtained is 22.61 W/m^2K.

The overall heat transfer coefficient for the design so calculated is 17.31 W/m^2K. Hence, from the basic heat transfer relation the area of roll bond evaporator is found out to be 13.41 m^2.

For the first set of design conditions, i.e., keeping the temperature of condenser as 40°C, the design of roll bond evaporator is done by changing the evaporator temperatures. For the second set of design conditions, the temperature of condenser is fixed at 35°C and the design of roll bond evaporator is done by changing temperature of evaporator. The values so obtained are represented in Table 1.

The values of overall heat transfer coefficient as obtained by above calculations are plotted on a graph in Figure 3. It can be concluded from Figure 1 that the trend lines are the same for both 40°C and 35°C, as

TABLE 1. Summary of data obtained from design calculations, fixing the temperature of condenser as 40°C and 35°C

Overall Heat transfer Coefficient			
Sl. No	Temp of refrigerant in Evaporator	Temp of refrigerant in condenser 40 °C	35 °C
	°C	W/m^2K	W/m^2K
1	0	17.3	17.27
2	5	17.27	17.24
3	10	17.25	17.23
4	15	17.23	17.21

exhibited by the numerical relation of overall heat transfer coefficient. Hence the above design procedure can be used for roll bond evaporator in a room air conditioner.

4. EXPERIMENTAL COMPARISON BETWEEN A TUBE AND FIN EVAPORATOR AND A ROLL BOND EVAPORATOR WHICH IS TO BE USED IN ROOM AIR CONDITIONER.

An experimental setup has been prepared to compare performance of roll bond evaporator with that of tube and fin evaporator. As per the standards of National Accreditation Board of Testing and Calibration Standards, (Government of India), and IS 1391 (1992) Part I standards, an experimental setup was established and measurement system was calibrated.Eight thermocouples are used for measurement of temperature. The accuracy of measurement of using thermocouple is 0.1°C. Figures 4, 5 6 and 7 show a tube and fin evaporator, roll bond evaporator, data acquisition system for tube and fin evaporator and data acquisition system for roll bond evaporator, respectively.

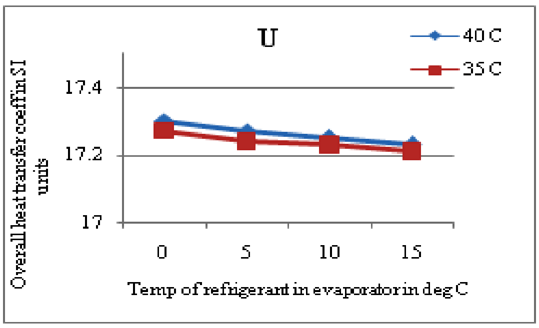

Figure 3. Variation of Overall heat transfer coefficient with temp of evaporator at different condenser temperatures

A room of dimensions 12 feet x 12 feet x 12 feet has been set up for experimentation. Experiments have been done to evaluate the following two system parameters for both the evaporators.

(i) Temperature distribution on any plane selected at random, as a function of time i.e. T(x,y,z,t) will be measured.

Figure 4. Room AC with tube and fin evaporator

Figure 5. Roll bond evaporator

Figure 6. DAQ for tube and fin evaporator

Figure 7. DAQ for roll bond evaporator

'x' is length, 'y' height and 'z' width of the room, 't' being measured time. In this experiment a vertical plane is selected at a distance half of the length of the room. Four thermocouples are placed on the plane at random to find the temperature distribution on the plane, measured as a function of time. The four thermocouples placed in the room at a plane are TC 1 (a/2,a/4,a/4), TC 2 (a/2,3a/4,a/4), TC 3 (a/2,a/4,a/2) and TC 4 (a/2,3a/4,a/2) where ' a' is dimension of the room. The positions of these thermocouples are as shown in Figure 8.

(ii) Temperature distribution in the total room, so as to find how uniformly the cooling effect is being felt. Another four thermocouples are used which measure temperature as a function of i.e. T (x,y,z,t). The four thermocouples placed are TC5(a/4,a/4,a/4) TC 6 (a/2,a/2,a/2), TC 7 (3a/4,a/4,3a/4) and TC 8 (3a/4, 3a/4,3a/4).

4. 1. Results from Experimentation

The results so obtained from experimentation are tabulated in Tables 2 and 3.

4. 1. 1. Graphs for the Results Obtained from Experimentation and Conclusions from Graphs

The following section shows graphs for temperature distribution on a plane kept at a distance of 'a/2' from the wall on which roll bond evaporator/tube and fin evaporator is kept.

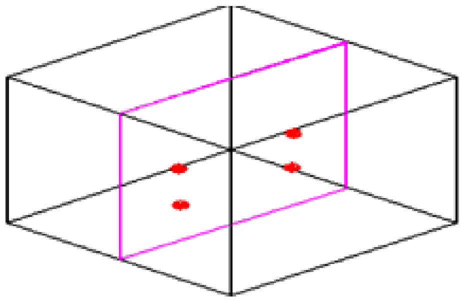

Figure 8. Positions of thermocouples on the plane

TABLE 2. Temperatures at Thermo couples (TC1,2,3 and 4) on a selected plane, for both Roll bond (RB) evaporator and Tube and Fin (TF) evaporator

Time in min	TC 1		TC 2		TC 3		TC 4	
	RB	TF	RB	TF	RB	TF	RB	TF
0	29.9	30.1	30	30	30.1	30.2	30.1	29.9
5	29.4	26.1	29.8	29.8	26.1	26	27.2	30
10	29	23.8	29.4	29.4	23.8	23.4	24.9	29.5
15	28.3	23	28.7	28.7	23	22.8	23.4	28.8
20	28	22.3	28.3	28.3	22.3	22	23.1	28.5
25	27.1	22	28	28	22	22	23	28

TABLE 3. Temperatures at Thermo couples (TC 5,6,7,8) placed at four different points in the room, for both Roll bond (RB) evaporator and Tube and Fin (TF) evaporator

Time in min	TC 5	TC 6	TC 7	TC 8
0	29.9	30	30.1	30.1
10	27.7	26.8	27.2	27.9
15	26.9	25.8	26.9	27.2
15	26.9	25.8	26.9	27.2
25	25.9	24.1	26	26.6
30	25.1	24.1	25.6	25.9

Figures 9, 10, 11 and 12 give variation of temperature with time for four different thermocouples.

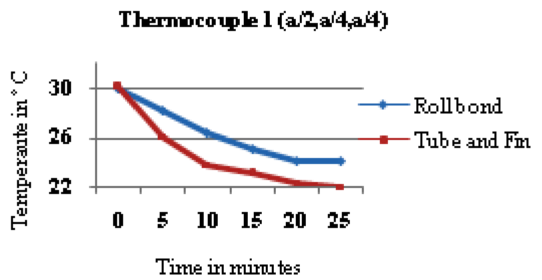

Figure 9. Temperature recorded by TC1

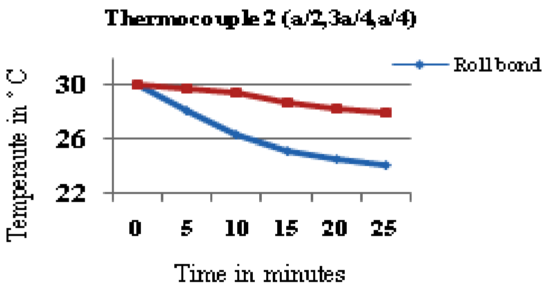

Figure 10. Temperature recorded by TC2

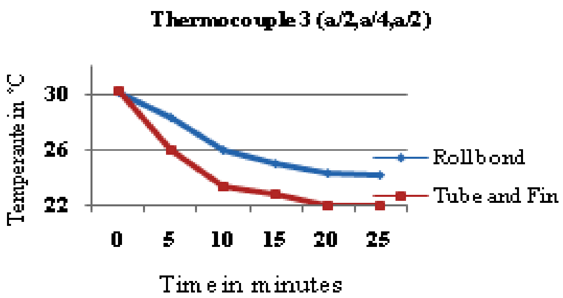

Figure 11. Temperature recorded by TC3

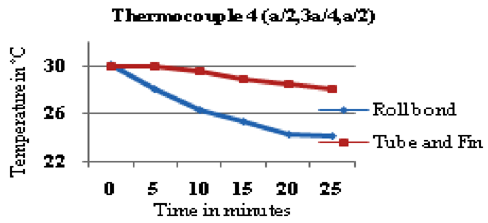

Figure 12. Temperature recorded by TC4

Conclusions from the above graphs:

Figures 9 and 11 show that in the region directly in front of tube and fin evaporator the cooling is more as compared to roll bond evaporator. Figures 10 and 12 show that in all other regions the temperatures obtained by roll bond evaporator is lesser than that of tube and fin evaporator.

Figures 13 and 14 show variation of temperature on the reference plane for both tube and fin evaporator and roll bond evaporator.

Conclusions from the above graphs:

Figure 13 shows that by using tube and fin evaporator uniform cooling is not possible. Figure 14 shows that the temperature on the plane becomes 24°C in 20 minutes for a roll bond evaporator.

The following section shows graphs to find uniformity of temperature distribution at four different points in a room when roll bond evaporator and a tube and fin evaporator is kept. Figures 15, 16, 17 and 18 give variation of temperature with time for four different thermocouples

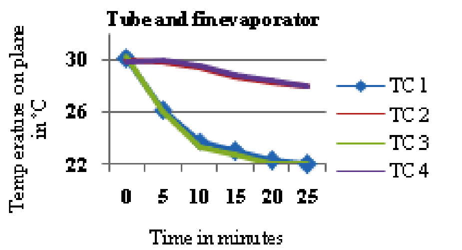

Figure 13. Temperature recorded by thermocouples (TC 1 to TC 4) when tube and fin evaporator is used

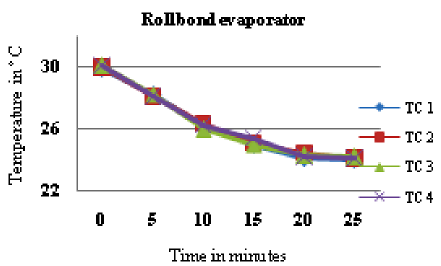

Figure 14. Temperature recorded by thermo couples (TC 1 to TC 4) when roll bond evaporator is used

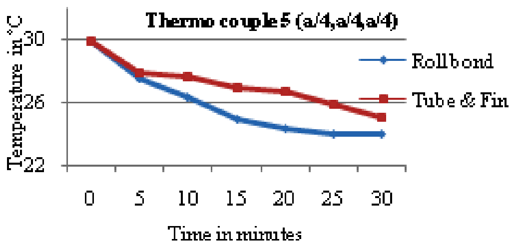

Figure 15. Temperature recorded by TC5

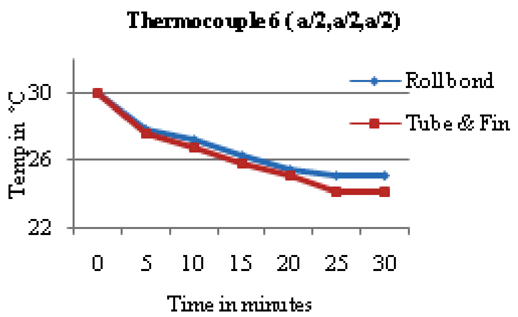

Figure 16. Temperature recorded by TC6

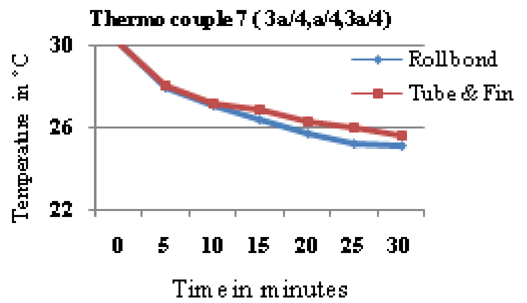

Figure 17. Temperature recorded by TC7

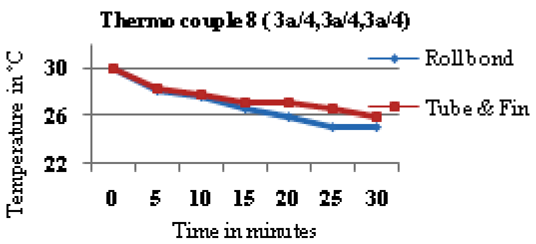

Figure 18. Temperature recorded by TC8

Conclusions from the above graphs:

1. Thermocouples 5, 7 and 8 show that at every instant of time, roll bond evaporator gives more cooling than tube and fin evaporator.
2. Thermocouple 6 shows that cooling performance of tube and fin evaporator is superior to roll bond evaporator. It is due to the fact that Thermocouple 6 is directly in front of tube and fin evaporator.
3. This shows that the temperature as obtained by roll bond evaporator is less than tube and fin evaporator in almost all regions. Only in the region directly in front of tube and fin evaporator, cooling is rapid. But in the other region cooling is not uniform, whereas in case of roll bond evaporator, temperature at almost all places in the room is superior to tube and fin evaporator.

The following section shows Figures 19 and 20 to find uniformity of temperature distribution in the room comparing roll bond evaporator with tube and fin evaporator.

Conclusions from above graphs

1. In case of roll bond evaporator, it took around 26 minutes to get a uniform temperature of 25°C in the room. (Thermocouple 8 shows less temperature as compared to all the other as it is near to the surface of roll bond evaporator).
2. In case of tube and fin evaporator, it took around 30 minutes to get a uniform temperature of 25°C in the room. Thermocouple 6 shows less temperature as compared to all the other as it is directly in front of tube and fin evaporator. The above two observations clearly show that the roll bond evaporator gives uniform cooling in less time.
3. In the region directly in front of tube and fin evaporator, cooling is rapid. But in the other region cooling is not uniform. Whereas in case of roll bond evaporator, temperature at almost all places in the room is superior to tube and fin evaporator.

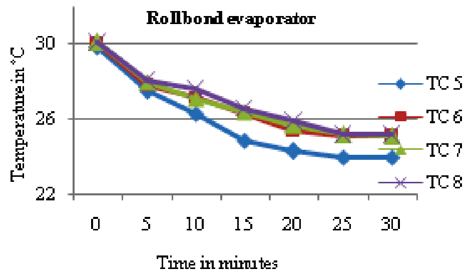

Figure 19. Temperature variations for roll bond evaporator

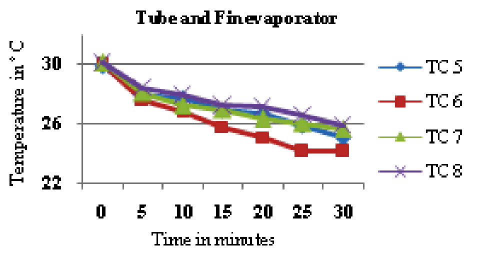

Figure 20. Temperature variations for tube and fin evaporator

5. CALCULATIONS FOR ENERGY SAVINGS

For the present experiment, a 1½ TR air conditioner is considered, which has a compressor of 7.35 kW capacity. The experiment is carried out with this compressor using tube and fin evaporator and next a roll bond evaporator.

To get uniform temperature, the roll bond evaporator takes 5 minutes less when compared to tube and fin evaporator. The energy saving for these 5 minutes will be 441 kJ or 0.624 kW-h, for every 30 minutes of working. On an average, if this air conditioner works for 6 hours a day, there will be a saving of 7.488 kW-h of energy per day. In other words, if the tube and fin evaporator works for 6 hours, the roll bond evaporator works for 5 ½ hours only. This shows that roll bond evaporator will contribute to reducing global warming phenomenon.

6. CONCLUSIONS

From the above design and experimentation, it can be concluded that the evaporator manufactured from roll bond process gives more uniform cooling than the traditional tube and fin evaporator, when used in 1½ TR air conditioner. Hence it saves power.

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Design and Experimentation of Roll Bond Evaporator for Room Air Conditioner with R-22 as Refrigerant

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چکیده

جهان به دنبال تولید محصولات با صرف انرژی کمتر بدون فدا کردن کیفیت زندگی است. افزایش استفاده از لوازم تبرید و تهویه مطبوع به بالا بردن گرمای کره زمین کمک می‌کند. دمای زمین با آهنگی شتابان به صورت سراسری در حال افزایش است. در این مقاله یک اواپراتور نوردشده به عنوان گزینه‌ای برای جایگزینی مبادله‌کن حرارتی مورد استفاده در کار خنک کردن فضاهای زندگی معرفی شده است. در حال حاضر تمام سیستم‌های تهویه مطبوع از اواپراتور لوله و پره‌ای استفاده می‌کنند. در مطالعه‌ی حاضر اواپراتور نوردشده به عنوان جای‌گزینی برای اواپراتورهای لوله و پره‌ای به منظور کاهش مصرف انرژی بررسی و مقایسه بین آنها انجام شده است. مشخص شد که زمان لازم اواپراتورهای لوله و پره‌ای برای رسیدن به دمای یک‌نواخت ۲۵ درجه‌ی سانتی‌گراد ۳۰ دقیقه، و برای اواپراتور نوردشده ۲۵ دقیقه است، یعنی ۵ دقیقه صرفه جویی در زمان کار سیستم تهویه مطبوع.

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